

A SYSTEM STUDY OF FIRE DANGER MONITORING NETWORK:
FINAL REPORT

Jerry D. Plunket

Final Report

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MONITORING NETWORK

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1.0 INTRODUCTION

1.1 Background

The increased and often conflicting demands placed upon the national forest lands by both the private and public sectors require that these lands be protected from disaster, natural or man-made. There is no more serious threat to a forest, its intricate and economically productive ecosystem, and human utilization of both than wild fire. In addition to laying open the land to water erosion, silting of streams, and killing of aquatic life, fire as an uncontrolled force destroys trees, wild life, and the aesthetic values of the forest.

Nevertheless, controlled burning is a valuable forestry tool, useful for the removal of excessive fuel from forest land by natural recycling and often necessary in the opening-up of new areas. Wildlife is less affected by controlled, slow-burning fires than by uncontrolled wildfires. In fact, it is probably not possible to properly manage U. S. Forest lands without the careful and controlled use of burning.

Fortunately, forestry science has now progressed to the point that in principle the basic factors controlling both the behavior and consequences of fires are rather well understood. What remains is to translate this fundamental knowledge into a workable real-time system.

Proper forest management depends upon a complex system of decision-making carried on by a large number of people operating at different levels of concern with different objectives. In order that this decision-making process might be made more effective, it is necessary that physical factors of fire occurrence be reduced to a quantitative basis operating in a real time framework.

Such a system described by Deaming et al. (1), allows the immediate use of information relative to local forest conditions and basic meteorological data; such data would, for example, enable forest personnel to control burning effectively, minimize wildlife losses, and reduce costs. The recent development of an improved, stable fuel-moisture analog completes the system. Because of the promise shown by the analog and its importance to the system, it is appropriate here to outline the purpose, scope, and objectives of National Fire Danger Data System (NFDDS), to identify likely systems problems, and to recommend the most promising solutions.

1.2 Scope

This study sets forth the general requirements of the NFDDS as a real time information and control system. In certain areas, sufficient information is not available to completely design the system; these areas are identified.

An overall national system is defined and those areas least understood have been studied most intensely; for example, the sensor-to-Base Station requirements. Fire Weather remote sites, the Flammability remote sites, the Base Station, the sensors, the communication system, and the processing and formatting of the output data are described. Specifically, this study defines the physical functions of the remote and Base Stations, the communication alternatives, and recommends the optimum system on the basis of cost, reliability, and general utility as determined by engineering judgment and experience.

1.3 Objectives

The objectives of this study were to obtain information, and general inputs to detailed planning and design studies that will further advance the design of the final system. To this end the following tasks were completed:

1. Describe alternate information systems suitable for this application, listing requirements and design goals.
2. Describe alternate methods for collecting and utilizing of data from a comprehensive fire danger station network in real time.
3. Describe alternate approaches to result in sufficient cost reliability information to support a decision on the final configuration of such a monitoring net work in conceptual terms. Specific hardware recommendations are not given.

In order to complete these tasks the following areas of technical work were studied in detail and covered in considerable detail.

1. An evaluation of several representative currently-operational remote weather measuring networks.
2. A summary of the important findings resulting from the three tasks contained in the objectives, based upon general engineering judgment and experience.

2.0 BASIC SYSTEM DESCRIPTION

2.1 National Fire Danger Data System Basic Requirements

The organization of the NFDDS is given in Figure II-1. In essence this system consists of four sub-systems. These are:

1. National Fire Danger System Headquarters (NFDSH).
2. Regional Fire Danger Stations
3. Base Stations
4. Remote Sites

These four (4) sub-systems are linked together into a network to allow the transmission of data and the communication of commands and information to provide a system by which maximum use can be made of controlled fires and to minimize the damage arising from wildfires. This section provides a description of the functions of each of the four levels described above in terms of their basic requirements. It is understood that the various sub-systems requirements are only very generally defined. As these sub-systems begin to function further requirements will arise that will increase the load carried by the communications network but will probably not require an major system modification for a considerable period of time.

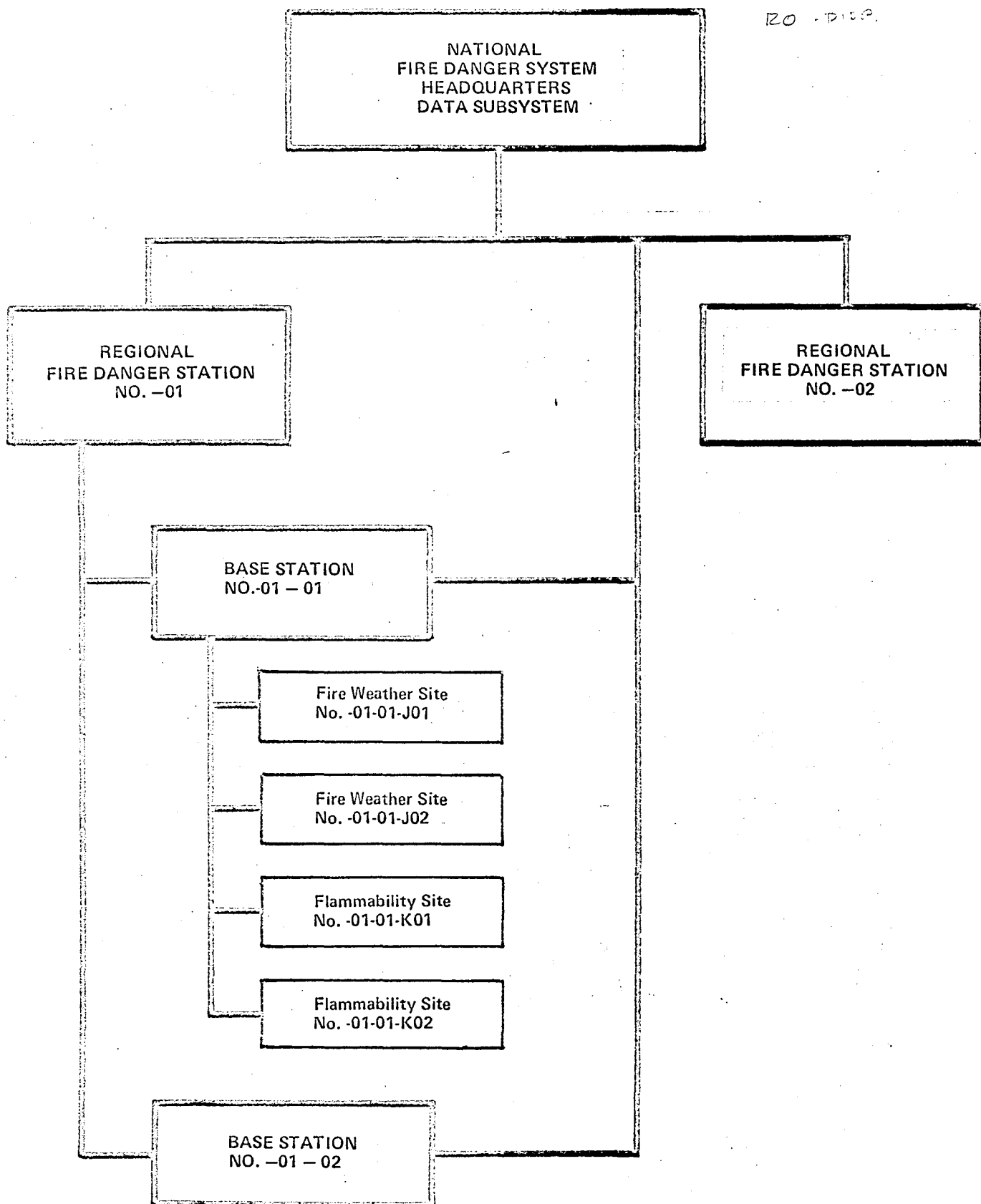
This information and data system is designed to serve the existing Forest Service management structure. The present Forest Service organization has evolved over a period of approximately sixty years and has been developed, modified, and revised to fit a unique set of forest management problems and public needs well beyond fire control and suppression. Therefore, the NFDDS is designed to serve as one part of a large pre-existing management organization. The NFDDS should serve to strengthen the present organization by making larger and more quantitative pertinent data available more rapidly at all organizational levels.

National Fire Danger System Headquarters Sub-System (NFDSH)

The NFDSH is the principal and top command point for the full NFDDS. Its purpose is to provide the following:

1. Establish all policy, operations, and functions of the NFDDS.
2. Obtain resources to support all NFDDS functions and activities.
3. Establish priorities for the allocation of resources and set national guidelines.

FIGURE II-1 NATIONAL FIRE DANGER DATA SYSTEM COMMAND
AND DATA LINKS. OVERALL COMMAND AND DATA LINKS.



4. Direct the deployment of all Fire suppression and control personnel equipment, and facilities in times of major danger.
5. Serve as a command center in times of National fire emergencies.
6. Provide a repository for all permanent records of data and information collected by the NFDDS.

This list of six items is not to be limiting but serves to give a general description of the extent, nature, and type of activities occurring at the NFDSH.

Regional Fire Danger Stations (RFDS)

Reporting to the National Headquarters (NFDSH) will be a series of Regional Fire Danger Stations (RFDS). These stations will be assigned a particular geographic area and will serve as a central command, computation center, and control function within their assigned area. The RFDS will normally serve to meet their own needs in terms of fire danger response except when asked to provide assistance to other regional units or to ask for additional assistance in times of emergency periods.

The following activities illustrate the functions of the RFDS.

1. Following the policy and procedure established by NFDSH direct all operations within their region.
2. Allocate resources and set priorities for all functions within their regions.
3. Serve as a command center for all regional fire control activities.
4. Provide a computation capacity and a communications center to serve all base stations in their region.
5. Maintain a library of data and information required for the NFDDS and its operations.
6. Possess the communications capability of reaching the NFDSH, other surrounding Regional Stations, or directly.

Base Stations

Reporting to the Regional Fire Danger Stations will be several Base Stations placed at selected locations based upon the basic Forest Service fire control organization. These base stations will serve as collector units for information and data obtained from a series of satellite remote sensors. Base stations will be equipped with only the controllers of computing capacity

necessary to obtain and format sensor data. No attempt, at present, should be made to compute fire danger indexes from the sensor data.

Base stations should serve the following functions:

1. Command surrounding sensors to provide data either on a preselected routine or as requested by the operator.
2. Assemble, reformat data, and store sensor data both for local display and to send to Regional Fire Danger Stations.
3. Provide a regular report on the status and condition of all remote sites and sensors.
4. As spare time is available provide computing capacity for timber growth calculations, sales estimates and other miscellaneous services.

Remote Sites

At predetermined and carefully selected remote sites will be a collection of sensors to directly measure meteorological and fuel moisture data as the basic environmental system interface. Remote sites will be comprised of two types: flammability sites and more elaborate but less numerous fire weather sites. A fuller description of the remote sites, their sensor requirements and characteristics will be given later based upon Forest Service fire danger index needs.

2.2 Detailed Description of the Fire Danger Rating System

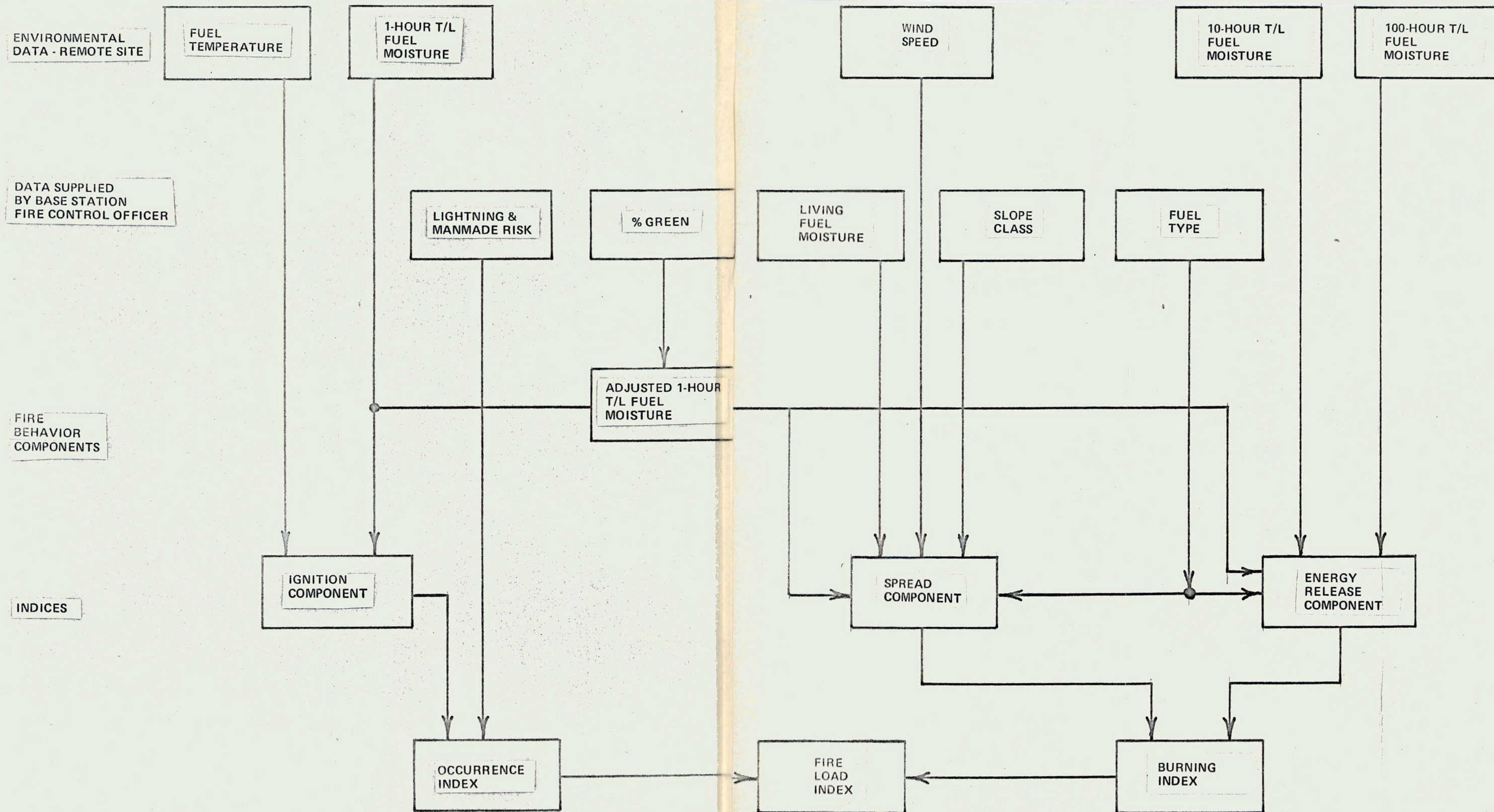
The Fire Danger Rating System (FDRS) consist of a detailed mathematical model of the important variables relating fire behavior in forests to two different levels of input data. This input data is in turn used to calculate a set of fire behavior components and a set of indices. Figure II-2 is a schematic representation of the input-output connections shown without the detailed mathematical relationships.

The basic environmental data provided by the flammability sense the following six (6) sensors: Fuel temperature, wind speed, and one hour, 10 hour, and 100 hour log fuel moisture contents of air exposed sensors plus one fuel moisture 10 hour sensor buried in the forest duff. These parameters will be described in greater detail in section 4.6.

Combined with this real time environmental data are five types of information supplied by the base station fire control officer. This information includes:

1. Lightning and Man-made Risk.

FIGURE II-2 U.S. FOREST SERVICE NATIONAL FIRE DANGER RATING SYSTEM



2. Percent Green Material.
3. Living Fuel Moisture.
4. Slope class.
5. Fuel types.

As can be seen some of these factors are fixed permanently while others can vary at broadly different rates. Fuel types vary as a function of season and over several years, while percent green and living fuel can undergo appreciable change in a matter of weeks. The most rapidly changing parameter and a highly significant one is the lightning and man-made risk.

The following is a description of the information supplied by the Base Station Fire Control Officer.

1. Lightning and Man-made Risk

A numerical factor related to the probable number of lightning strikes that reach the ground or the number of man-caused ignitions or firebrands occurring within the given protection area. Established Forest Service procedures have been developed for determining this risk. In general this risk factor is set on a daily basis, but is subject to a more time dependent variation in a real time system. For example the development of a particular cold front movement and the thunderstorms arising from this front could be followed by a series of remote sensor stations.

After a period of years the base station data bank could provide a close stochastic historical index for this number. Thus after a reasonable period of time this input factor can be refined.

2. Percent Green (PG)

The volume percent of fine fuel in the total biomass which is living and above the surface of the ground is represented by the parameter. A series of percent green curves for different areas can be generated by inspection trips to various vegetation types over a period of years. This data would then be modified to conform to seasonal weather differences.

Initially new PG data would be supplied weekly for the Spring and Autumn seasons, but monthly in Winter and Summer. After a period of years these step functions could be converted into curves that vary day by day and can thus be seasonally adjusted.

3. Living Fuel Moisture

The moisture content of living woody materials such as leaves and small twigs can be given in three levels: rapid growth, slow growth (maturity) or severe drouth (partial dehydration). Moisture contents of these three classes are: greater than 125%, 75 to 125%, and less than 75% respectively.

This level of information will vary on a weekly basis and can be adjusted accordingly.

4. Slope Classes

The slope of the general topography of an area can be provided with sufficient accuracy by three classes.

0 to 20% Slopes

21 to 40% Slopes

40° or more Slopes

As previously mentioned slope classes do not change as a function of time.

5. Fuel Types

The fire danger rating system (NFDRS) classifies fuels into one of eight types. The selection of an appropriate fuel type for a given area is a rather sophisticated forestry decision and will not be discussed except that the fire control officer will select the type representative of given areas under his purview.

The combination of real time environmental data with the information supplied by the Base Station Fire Control Officer to determine via the base station computer facility three fire behavior components which are summarized as follows:

1. Ignition Component

The ignition component indicates the probability that a fire will develop if a firebrand is introduced. Closely related is the spotting potential for a fire after it has started.

2. Spread Component

Once a fire is started the spread component measures the probably rate at which the burning front (head) will move. The fire control

officer can then make an estimate of the time necessary for control crews to reach a given fire area, the length of fire control line that will be required, and thus the control crew needed.

3. Energy Release Component

The intensity of a flaming front at the head of a fire is measured by the energy release component. This factor measures the width of a control line that must be cleared. This is also a factor in the size and type of control equipment deployed for a given fire.

A further combination of the above three components with the risk factor allows the three final indexes to be determined. In a very general way these three indexes can be described as follows:

1. Occurrence Index

The occurrence index is a direct measure of the potential of fire incidence for any given period of time.

2. Burning Index

This index is a direct measure of the total effort needed to suppress and control an average fire.

3. Fire Load Index

The fire load index measures the most likely effort required to contain all probable fires during a given day for a particular area.

2.3 Upper Level NFDDS Sub-System Problems

As shown in Figure I-II the upper level communications network consists of the transfer of purely digital data from Base Stations to Regional Fire Danger Stations and on to the National Headquarters. By virtue of the fact that the Base Station has error checked the data, and formatted data for communication this network is all within the state-of-the-art. Numerous nationwide communication systems of this type exist and the Forest Service can describe the general size of the annual information flow anticipated and can seek bids for this utility service. Therefore we see no point in discussing further the general or the specific details of these requirements at this time.

2.4 Base Station to Remote Sites Sub-System Requirements: The Critical Undeveloped System Segment

Base Stations located at various geographical places, usually ranger stations, require automatic data systems to collect data from sensor located

at two types of remote sites: Fire Weather Sites and Flammability Sites. All sensor data first appears as analog data and must be converted to digital form, checked for errors, edited, and stored for transmission to the Regional Fire Danger Station for use in calculating the various fire indexes.

The U.S. Weather Service as well as the U.S. Forest Service has previously purchased remote weather station generally similar to that used in the remote sites. There have been numerous problems relating to cost effectiveness, reliability, accuracy, etc. for this equipment. In contrast to hundreds of national data links this remote site equipment is underdeveloped and plagued with problems. It is the major difficulty of the National Fire Danger data System to overcome these problems.

The major purpose of this report is to identify these problems, discuss alternative approaches that appear useful, and then to recommend minimum cost in terms of dollars, effort and time approach to reducing or preferably overcoming these difficulties and limitations.

The base station, remote site, equipment, sensors, and communication links are the most significant and critical problems to be solved.

3.0 EXAMINATION OF EXISTING REMOTE WEATHER STATIONS

3.1 Introduction

This section describes studies of three systems designed to transmit meteorological data from one or more remote locations to a central collection point. Two of the systems are maintained by the U.S. Forest Service in the Shoshone (Wyoming) and Boise (Idaho) National Forests and one by the National Weather Service in Silver Spring, Maryland. While their functions are basically the same, the three stations represent distinctly different approaches to the problem of encoding and transmitting meteorological information. It is the purpose of this section to identify both the most desirable and undesirable features of each system, and from these observations, develop concepts for use in the proposed National Fire Danger Rating System. We have therefore attempted to describe each of the systems with particular attention to the following:

1. The kinds of measurements being made.
2. The versatility of the system; e.g., the number and type of sensors being monitored, and provision for additional sensors.
3. The method of converting the analog signals from the various sensors into forms suitable for transmission to the central station.
4. The communication links used to interrogate the remote station and receive information from the station.
5. The time required to interrogate the remote station and for the station to transmit the required information, the frequency of interrogation, and the provision for manual interrogation.
6. The accuracy of the data gathered by the sensors and transmitted by the remote station.
7. The maintenance requirements of the system.
8. The power requirements of the system.
9. The initial costs of the system and its components.
10. Operational probability of the system.
11. The particular problems of the system to be avoided in the proposed new system.
12. Any unique and desirable features of the station which might be considered for incorporation in the proposed new system.

3.2 The U.S. Forest Service Boise System

The Boise System is an ARMAC 2084 Automatic Fire Weather System, manufactured by Meteorological Research Institute. The central station and three remote stations are all presently located in a Forest Service compound at Boise, Idaho. The remote stations were initially deployed in the Boise National Forest, but were withdrawn after a brief trial period in which the performance of the system fell short of Forest Service operational requirement, particularly with respect to battery depletion and replacement intervals.

3.2.1 The ARMAC 2084 Central Station

The Central Station at Boise features an automatic unit which performs the following functions:

1. Generates and displays time of day signals.
2. Provides manual controls to set interrogation intervals.
3. Generates the remote station address codes.
4. Provides appropriate signals for modulation of the radio transmitter in order to selectively interrogate the remote stations.
5. Generates timing signals required for digital discrimination, encoding, and data transfer.
6. Shapes incoming information from the remote stations for processing.
7. Performs arithmetic functions to convert wind distance to wind speed.
8. Scales and stores data in a form suitable for printing.
9. Provides a form of calibration and various troubleshooting aids.

In addition to the central automatic unit, the central station utilizes a Franklin Model 120A strip printer and a Motorola Model L4366B-3100 transceiver, modified to operate as a selective call unit. The ARMAC 2084 central station has the capability of handling ten remote stations.

3.2.2 The ARMAC 2084 Remote Stations

The remote stations actually consist of five separate units. The radio transceiver is housed in a pole mounted enclosure atop which the wind speed and direction instruments are mounted with temperature and humidity sensors below. The MRI Model 302 tipping bucket rain gage occupies a unit by itself. The three remaining units are cylindrical field containers designed for burial at the remote site, and house the electronics package, batteries for the electronics package, and batteries for the radio.

The remote station electronics package was designed for ten channels, although only eight are presently used. Two are required for the wind speed sensor, and one each for wind direction, temperature, relative humidity, and accumulated moisture sensors. In addition, one channel is used for a VFO zero-signal check and one for a battery voltage measurement. The VFO zero-signal frequency check provides a measure of automatic compensation, at the central station, for frequency variations in the voltage controlled oscillators in the remote electronics packages. This feature is discussed further in Section 3.2.6 of this report.

3.2.3 Sensors

Wind Speed

The wind speed is determined by measuring the time required for the passage of a constant 687 feet of wind, using a cup anemometer with three 4 1/2-inch conical aluminum cups. Two time words are required to establish the wind distance time. The time base fixes the general speed range and the vernier time allows determination of wind speed to within 1 mph. The two times are referred to as "wind time A" and "wind time B". At low wind speeds, several minutes may be required for the passage of 687 feet of wind. The two time words for the previous 687 feet are therefore held in storage, and it is these words that are transmitted upon interrogation. Upon the accumulation of the next 687 feet of wind, the time base generator is reset, and the two wind speed words transferred to storage, replacing the previous measurements. The accuracy of the measurement is determined entirely by the vernier time, wind time B. The time base portion utilizes a predetermined three-step voltage, or VCO frequency, to establish the general speed range.

Wind Direction

The wind direction is sensed by a ball-bearing-mounted, balanced, single-blade aluminum vane with nose damping, located immediately below the anemometer, so that both wind direction and speed are representative of a single point in space. The total length of the vane is 33 1/2 inches, permitting the device to operate at speeds as low as 0.75 mph. According to the specifications, the overall accuracy of the instrument is $\pm 1\%$ of full scale.

Temperature

The temperature is measured by an MRI wire thermometer, which operates over a -40 to $+130^{\circ}\text{F}$ temperature range. The thermometer is constructed of isonel-varnished copper wire wound on an aerated teflon form. The device is accurate to within $\pm 0.2^{\circ}\text{F}$, according to the MRI instruction manual.

Relative Humidity

The relative humidity sensor utilizes eight hygroscopic sensing elements with overlapping ranges. Accuracy of the sensor is $\pm 3\%$ relative humidity, between 40 and 120°F . The range of the instrument is 10 to 90% relative humidity.

Rain Gage

Finally, the MRI Model 302 tripping-bucket rain gage measures accumulated moisture to within $\pm 1\%$ at 2 in/hr, or $\pm 5\%$ at 10 in/hr. The collector has an inside diameter of 7.96 in., and a height of 24 in. overall. This resolution of the instrument is 0.01 in. per recording step, 7.95 ml water being required for one tip of the tilting bucket.

3.2.4 Radios

As mentioned previously, the central station employs a Motorola Model L43GGB-3100 25-watt transceiver operating on 166.675 and 170.575 MHz.

The remote stations provided by Meteorological Research Institute utilized battery-powered Motorola transceivers with 2.2 watts output power.

3.2.5 Power Requirements

The components of the central station are all designed to utilize commercial power at 115 VAC, 60 Hz.

The portable radios supplied with the remote stations require -12 to -15 volts. This is normally supplied by twelve "D" flashlight cells within the radio; however, the remote stations here described were designed to operate for 28 days, and used 1.5-volt telephone-igniter batteries located within the cylindrical battery packs which are buriable at the remote site. In order to facilitate non periodic interrogation, the receiver must operate continuously, and draws about 4.5 mA. The transmitter, in operation but infrequently and then only briefly, would require hundreds of times this current.

Fortunately, the interrogation sequence normally occurs only about four times each day, at which times the transmitter is on for about two minutes, according to the instruction manual. More frequent interrogation is possible, of course, but would require even more energy from the radio battery package.

The meteorological equipment and electronic package require +12 to +15 volts, also supplied by telephone igniter batteries in a buriable container similar to that housing the radio batteries. According to the electronics technician at Boise, the anemometer is largely responsible for a rapid depletion of the batteries, drawing about 35 mA continuously. The other sensors operate only briefly during interrogation, and cause almost negligible depletion by comparison.

3.2.6 Remote Station Sequence of Operation

The remote stations are interrogated by a 15-second signal from the central station. The R.F. signal is modulated by an audio tone of about 100 Hz, the exact frequency depending on the particular station.

Upon receipt of the appropriate signal, the station call unit within the receiver of the remote station causes a relay to be closed, thereby supplying power to all the remaining circuits at the remote site. A sequencer in the electronic package is grounded and the zero-signal frequency is transmitted by the VCO. As previously mentioned, this signal is used by the central station to compensate for frequency drift of the VCO.

Following the zero-signal transmission the sequencer is stopped to its second position, in which the first wind speed work, wind time A,

is transmitted. The sequencer is then switched to a reference voltage which drives the VCO near its upper frequency limit, for transmission of wind time B, and precipitation, stored in digital form in the electronics package. Following transmission of the precipitation word, another sequencer switches the VCO to the remaining sensors for transmission of the air temperature, relative humidity, wind direction and battery voltage words. Although the VCO is switched from one sensor to another in negligible time, a gating device is utilized to eliminate switching transients and allows the VCO to stabilize before allowing transmission of the 270 ms word. The entire sequence is followed by a 100 ms delay before the power is removed to complete the remote station cycle.

3.2.7 Cost and Reliability Estimates for the Boise System

Table III-I shows the cost and 60/month operational probabilities for individual components of the ARMAC 2084 remote stations, using 1972 National Weather Service estimates for costs and individual 6-month probabilities of commercially available equipment. For computational purposes, it must be assumed that the present dry-battery packs would be replaced by a suitable combination of rechargeable storage batteries, and a means of electric power generation, in order to extend the maintenance interval to six months. In order to compare the system with others, we assumed a thermoelectric generator, for which figures were available, would be used.

The cost of the remote station would be about \$4940 including the proposed thermoelectric generator, of \$3940 in its present, unacceptable configuration, using dry batteries.

The overall operational probability of the system is given by the running product of the 6-month probabilities of the individual components.

$$P = \prod_{i=1}^n p_i$$

For the Boise system, the right member of the equation would have as factors the individual 6-month probabilities of each component, or nine factors in all. The overall probability is 0.066, meaning that the entire system, would have a 6.6 percent chance of completing the entire 6-month interval with all its components operating. The probability attributed to the sensors alone would be

$$P_{\text{sensors}} = (0.75)^n,$$

where n is the number of sensors, five in this case. Thus the probability of all the sensors surviving the entire period is only about 0.24. It is apparent that a complex system having a large number of sensors

TABLE III-I
COST AND RELIABILITY ESTIMATES FOR
THE ARMAC 2084 REMOTE STATIONS

ITEM	APPROX. COST	SIX-MONTH OPERATIONAL PROBABILITY
Radio Transceiver	900	0.35
Antenna	135	0.90
Electronics Pack	1000	0.95
Wind Speed Sensor	560	0.75
Wind Direction Sensor	620	0.75
Temperature Sensor	500	0.75
Relative Humidity Sensor	650	0.75
Cumulative Moisture Sensor	580	0.75
Thermo Electric Generator	1000	0.93

is incompatible with high overall operational probability. Presumably, the station would continue to function with the loss of one or more sensors, and the probability of a complete breakdown would be more remote. For example, the probability of the station surviving a 6-month interval with only one sensor would be

$$P(\text{station} + 1 \text{ sensor}) = 0.21$$

We further note that the radio transceiver has been assigned a 6-month operational probability of only 0.35. According to the National Weather Service, this figure is based on "currently available commercial systems," which they consider as a worst case. Ultimately, their goal is to achieve a figure of 0.70, or twice the present value. Clearly, such a development would double the overall operational probability, which is now severely limited by the low reliability of the radios.

In locations where commercial power and either hard wire or telephone communications can be utilized, the limiting probabilities are those associated with the sensors. For example, in a hard wire system utilizing commercial power with two sensors, a probability of about 0.50 might be entirely possible, as both the commercial power and the hardwire communications typically have operational probabilities in excess of 0.95, comparable with the electronics package.

3.2.8 Critical Analysis of the Boise Stations

This section of the report is based on published information, principally the MRI ARMAC 2084 Instruction Manual and telephone interviews with Forest Service employees who had worked with the ARMAC System.

The Boise system is quite versatile and compact, requiring no protective shelter, and provides features not found in the Shoshone system. Both the central and the remote stations are characterized by modern digital electronics made attractive only within the last several years by integrated circuits.

The system has incorporated at least a first-order means of internal standardization with its zero-signal frequency measurement feature. Furthermore, it has provided for monitoring the condition of the batteries at each interrogation, thereby making available to the central station, some indication, however unspecific, of impending failure.

The cost of the system, with the central station, and three remotes, with radios, antennas, and sensors was about \$16,000.

Unfortunately no detailed cost breakdown was available, but the overall cost would compare favorably with the Shoshone system.

One of the chief complaints appeared to be the frequency with which the batteries failed. The system was designed to operate for only 28 days without replacement of the dry batteries, whereas the remote sites anticipated in the proposed Fire Danger Rating System would almost certainly preclude such frequent replacement. Also, the more frequent interrogation desired in the proposed system would further decrease the replacement interval. Rechargeable batteries, coupled with a suitable charging device are almost a necessity in view of the desired 180 day maintenance interval. If the Soil Conservation Snow-Survey stations are to be integrated into the proposed system, an even greater maintenance interval might be required.

It was previously mentioned in Section 1.2.5 that the electronics package and the meteorological equipment have negative grounds, whereas the Motorola radios supplied for the system have positive grounds, although all require 12 to 15 volts D.C. In the system's present form, with separate battery pack for radios, the two different references are not particularly troublesome; however, charging of the batteries, particularly with low-voltage high-current devices as thermoelectric generators could cause compatibility problems easily avoided with a common reference. The time required for interrogation of the remote station, during which the radio and all sensors are on, seems excessive in view of the fact that each of the eight words requires only 270 ms.

Except for a few initial problems associated with the integrated circuits, the electronics package performed satisfactorily by itself. One major flaw surfaced, however, when it was discovered that the square waves produced by the VCO in the electronics package would not properly modulate the transmitter of the materials radios. This required a further, unexpected modification of the system. Our interviews also revealed that the delivery time for Motorola replacement parts was unacceptably long, particularly for radios with special modifications.

No other important problems with the Boise stations were noted in our interviews; however, the problems of power and compatibility are formidable indeed.

3.3 The U.S. Forest Shoshone System

The Shoshone remote stations are located in the Shoshone National Forest, near Cody, Wyoming. The central station is housed in the Fire Slurry

Base at the Cody Airport. There are presently four remote stations in operation. Three stations communicate with the base station via direct radio link and one via a Forest Service relay station, located about 70 miles distant from the remote station, and 60 miles from Cody. The system was completed in 1965 and installed at Cody in 1966 by RBM Controls, Inc.

3.3.1 The RBM Central Station

The RBM central station consists of a control unit interfaced with a modified Smith-Corona typewriter, and with the large Slurry-Base radio transceiver. The control unit is basically a simple electro-mechanical device, containing a timer which can be set to selectively interrogate the remote stations on the hour at 0-2300 hours via a 4-second audio tone. The tones are produced by vibrasonic relays, which modulate the r.f. signal of the transmitter. A set of vibrasonic relays also comprises the decoding mechanism which responds to audio modulation of the RF carrier transmitted by the remote stations. Still another series of relays is used to drive the typewriter. The unit has the capability of handling up to ten remote stations. It is presently set up to record time and station, generated at the control unit, wind direction, wind speed, relative humidity, temperature, and precipitation as received from the remote station being interrogated. About 36 seconds are required to interrogate a remote station. For all its relays the control unit is quite compact, and occupies but little space atop a small desk at the Slurry-Base. The Slurry-Base radio operates at comparatively low frequencies on two channels, 32.58 and 34.46 MHz. The entire central station was designed to operate at ambient temperatures on commercial 115 VAC power.

3.3.2 The RBM Remote Stations

The principal feature of the RBM remote stations near Cody is the system of relays which encode the analog signals from the sensors and modulate, with audio tones, the r.f. carrier of the radio transceiver. The stepping relays are quite large, and occupy a major portion of a standard electronics rack. The rack is housed with the radio, thermoelectric generator, and storage batteries in a fiberglass building about 5 feet square and 8 feet tall. The radio antenna, anemometer and wind-direction sensors are located atop a 30 foot tower near the enclosure. Liquid propane tanks for the generator are stored outside the building. A standard wooden shelter nearby houses the temperature and relative humidity sensors, and the tipping-bucket cumulative-moisture sensor is also located nearby, the entire installation being surrounded by a chain-link fence.

3.3.3 Sensors

Wind Speed

The wind speed sensor is a No. 9 x 150 "Forrester" magnetic anemometer produced by Western Fire Equipment Co., San Francisco, Calif., after cooperative development with the U.S. Forest Service Electronics Center. The device is 12 in. in diameter and 10.5 in high. A magnetically actuated mercury switch within the unit makes 60 contacts per minute at a wind speed of 60 mph. Hence the device is calibrated to 1/60 mile increments. Accuracy is ± 5 mph, according to maintenance personnel at Cody.

Wind Direction

Wind direction is measured by a single blade vane, similar in appearance to that described previously in section 1.1.3 but smaller. Apparently, several different types have been used in Cody. The one we examined was the AWS-2 standard Forest Service Meter, having eight contacts located radially about the axis. Thus recording only changes each 45 degrees.

Relative Humidity

The relative humidity sensor is the same as that used in the Boise system, described earlier in section 1.1.3, and measures relative humidity to within $\pm 3\%$ in the range 10 to 90% R.H. between 40 and 120°F. The latest model in use at Cody was the model 15-7012 Humidity Transducer manufactured by Hygrodynamics, Inc., Silver Springs, Maryland.

Rain Gage

The tipping-bucket rain gage is the Henry J. Green instrument, model No. 593, which requires 0.01 in. of moisture for each tip of the bucket. A magnetically operated switch is actuated by each tip of the bucket causing the stepping relay in the relay rack to advance by 1 in the second decimal place. According to maintenance personnel at Cody the gages occasionally experience "bucket rebound", causing multiple stepping of the relay. The device is designed to operate on 6 volts AC or DC. Once again a variety of rain gages have apparently been tried at Cody, and we observed several different models at the maintenance shops which had apparently been less satisfactory than the Green, Model 593.

Temperature

A wire thermometer was used to measure temperature at Cody, but we were unable to obtain descriptive literature or specifications for the device.

3.3.4 Radios

The base station at the Slurry base is interfaced to a large transceiver also at the slurry base. The remote stations use portable transceivers of 8 watts RF power. The station we visited used a Motorola unit, although other units had been tried. The model we observed was designed to operate continuously (receiver only) at something less than 2.5 watts. Newer models require only about 0.5 watts in the receiver-only mode. Once the station is interrogated and the transmitter turned on, about 135 watts is required by the radio, and an additional 15 watts by the motor drive and relays for a total of 150 watts. The station requires about 36 seconds to step through the 5 sensors, during which time the transmitter must be on, before turning to the receiver-only mode. The stations are presently interrogated at 5-hour intervals, and at this level, the radio power requirements are not excessive.

The 32-34 mHz frequencies used in the system have been responsible for some noise problems which could be eliminated by a change to 170 mHz.

3.3.5 Power Requirements

As with the Boise station, all components of the central station at Cody are designed for use on commercial power at 115 VAC, 60 Hz.

The power requirements for the remote stations are a bit awkward. The relays operate on 24-28 volts, while some of the sensors require 6 volts and the radios 12 to 15 volts D.C. Ordinary automobile storage batteries are used to provide the power. A thermoelectric generator and converter are used to recharge the batteries. The thermoelectric generator is supplied by two 100 lb. tanks located outside the fiberglass building at the station. About 200 pounds of propane powers the generator for the entire fire danger period of about 6 months.

3.3.6 Remote Station Sequence of Operation

The sequence of operation of the Shoshone system differs only in detail from the Boise system. In both systems the receiver operates continuously in order to receive the challenge signal from the central station. The Shoshone stations require a 4-second signal of about 100 Hz.

Receipt of the proper signal activates the balance of the station, providing power to the radio transmitter, the other relays, and the sensors. Three stepping relays, whose positions are determined by the level of the analog signal from the sensor, select the appropriate series of vibrasonic oscillators. The r.f. carrier is modulated by audio frequency signals from these oscillators. The sequence is then repeated for the next sensor until all have been polled.

Whereas the Boise system utilized a single VCO and multiplexer, the Shoshone stations employ a unique combination of vibrasonic oscillators to represent the three digits corresponding to the level of the sensor signal.

3.3.7 Estimate of Cost and Operational Probability of the Shoshone Remote Stations.

The 6-month operational probabilities of the Boise remote stations were estimated in Section 3.2.7. The overall probability estimate of the Shoshone System is obtained in similar fashion. Table III-II shows the probabilities of the individual components of the system. Here again the figures are representative of presently available commercial equipment, as determined June 1972 by the National Weather Service.

The equation relating the overall 6-month probability to the 6-month probabilities of the components is repeated here for convenience:

$$P = \prod_{i=1}^n p_i$$

The combined probabilities of the essential components of the station, that is, those components whose failure would preclude all response by the remote station is about 0.059. Hence the probability for even a minimal response (1 sensor) is only $(0.75)(0.059) = 0.044$. For the station with three sensors, $P = 0.025$. For the present 5-sensor configuration $P = 0.014$.

The low operational probabilities are, for the most part, attributable to the electromechanical nature of the system. The many relays and motor driven sequencers are simply not compatible with subfreezing temperatures which are often encountered in the area, even during the summer months.

TABLE III-II
COSTS AND SIX-MONTH OPERATIONAL PROBABILITIES FOR
INDIVIDUAL COMPONENTS OF THE SHOSHONE REMOTE STATIONS

COMPONENT	APPROX COST	6-MONTH OPERATIONAL PROBABILITY ESTIMATE
(1)Relay Unit	\$3400,	0.20
Radio Transceiver	900	0.35
Antenna and Tower	400	0.90
TEG and Converter	\$1000	0.93
Wind Speed Sensor	560	0.75
Wind Direction Sensor	620	0.75
Cumulative Moisture Sensor	580	0.75
Temperature Sensor	500	0.75
Relative Humidity Sensor	650	0.75
Fiberglass Shelter	800	----

(1)The operational probability of the relay unit is our estimate based on the frequency of maintenance in a normal fire danger season of about 6 months.

Cost of the remote station, including the fiberglass shelter and liquid propane tanks, would be almost \$10,000, of which about \$3400 is due to the relays. The sensors presently in use would cost about \$3000.

3.3.8 Critical Analysis and Summary of the Shoshone System

By present-day standards of electronic sophistication, almost exclusive, use of relays in the RBM system at Cody might be considered less than inspired. The relays seriously degrade the overall reliability of the system, and their large physical size necessitates a shelter of substantial size and initial cost. One of the chief complaints at present is the high maintenance cost of the system, which requires remote station repair at least once per month usually in the relay section. The relays are comparatively expensive, and a large inventory is required to keep the stations operative. Not all of the relays in the unit have plugs to permit modular changes. The high cost and large size of the complete unit virtually preclude unit replacement, thus requiring subsequent repair at the shop.

The system has no provision for internal standardization, and no means of detecting erroneous transmissions or impending failure of the remote stations of the base.

Another serious deficiency of the system appeared to be its lack of versatility. The base station is capable of automatic interrogation of only ten remote stations, and then only on the hour. The remote stations have no provision for additional sensors beyond the five presently being monitored. The time required for the response of the remote station when interrogated is about 36 seconds, which is not unreasonable for an electromechanical system. Nevertheless, a system of 30 remote stations would require about 18 minutes to interrogate. Since the Forest Service administrative and command frequencies are used, one might wish for a shorter response time. However, this system is very much faster than the Boise system, even though the latter features more modern electronic design, but required several minutes to respond.

We further noted that the base station, located at the slurry base in Cody, was only a few feet distant from a teletype machine which comprised the higher communications link for the base station.

A simple modification of the present system could couple the central station directly to the teletype. This would permit simultaneous retransmission of the data to other stations as it is received, and eliminate the typewriter presently connected to the station. It would also

provide for random interrogation of any remote station in the system from any location having a teletype. A teletype switch modification would provide for decoupling the central station from the teletype when the latter is required for normal communication. At present, the operator of the slurry base would have to copy the incoming data onto the teletype, after first receiving it on the typewriter.

Radio noise has occasionally interfered with interrogation of the remote stations and their response. Although the problem is not particularly serious, a frequency shift from the present 32-34 mHz to 120 mHz would greatly reduce it.

If the extensive use of relays in the system may have appeared a bit unimaginative, we were impressed by the construction, and surprised that the equipment could be kept as compact and attractive as it was.

The quality of the maintenance appeared to be excellent. Despite the low reliability of the equipment the system is operational. The electronics technician at Cody is fully acquainted with the entire system and its limitations. He has been willing to experiment with various components and has succeeded in improving the performance considerably.

Like the Boise stations, the anemometer constitutes the largest single current drain on the batteries, about 35 mA continuously. When the entire station is turned on by the interrogation signal, the radio transmitter uses energy at a rate in excess of 135 watts and the total power consumed by the station exceeds 150 watts. Fortunately, however, the 36-second time required for the response (about 1/4 the time required by the Boise Stations) is short enough so as not to impose an undue load on the batteries. In any case, the energy consumed by the radio is lower than used by the anemometer. Also the batteries are being continuously recharged by the thermoelectric generator. According to Cody Maintenance personnel, the number of batteries required for the stations was about twice the expected complement, and contributed to slightly increased maintenance costs. Also, the thermoelectric generators used more fuel than originally anticipated. Nevertheless, the Cody stations are at least nominally operational, and are generally performing the specific tasks they were designed for, albeit at higher cost and lower reliability that one might wish for.

The thermoelectric generator is one of the brighter aspects of the system. The Cody stations utilize a Telan U1-P generator of 9 watts (10A at 0.9V) which has proved to be a particularly reliable and trouble free, except for an initial spate of trouble with insects contaminating the catalytic bed in the burner. A UCI-24 DC to DC converter provides

for the increase in potential to the 24 volts necessary to charge the batteries. No difficulty with the converter has been experienced. Fuel for the generator is liquid propane gas supplied at 20 Psi.

3.4 United States Weather Service AMOS Systems

The U.S. Weather Service has developed a series of systems designed to record and report meteorological parameters dating back to the early 1940's. The latest in this series, and the one described in this report, is known by the acronym AMOS, the Automatic Meteorological Observing System. AMOS has been operational for about four years with three stations in the Silver Spring Maryland area, even while a newer and more advanced system, RAMOS, is presently under development.

3.4.1 The AMOS Remote Stations

The AMOS system utilizes the same central station-remote station concept as in both systems previously described, but differs substantially in several respects. The remote stations of AMOS are remote only in the sense that they are located at some distance from the central station. They are unusually accessible by Forest Service standards, and are designed to operate entirely on commercial power using common-carrier communications. They require no radios and batteries, and no means of on-site power generation. Nevertheless, the AMOS stations have several particularly attractive features which could be incorporated in the proposed stations of the Fire Danger Rating System. The AMOS remote stations feature extensive use of integrated circuits, so that the entire electronics package occupies only a single 19" x 9 3/4" panel rack. AMOS is capable of monitoring up to 13 sensors, although only 9 channels are presently used. The remote stations are internally self checking to a considerable degree. When errors are detected, the error signal M is transmitted instead of the faulty data. The stations are presently being automatically interrogated at 20-minute intervals, but any desired interval may be used, as well as manual interrogation at any time. While the electronics pack is capable of continuous response, the 100-wpm speed of the teletype writer limits the transmission rate.

The format of the output message is as follows:

At the time the remote station is polled the central station prints a 3-digit central station identifier and a date-time group. For example:

123 09 1510

The response of the remote station is a 2-letter remote station identifier, say AA, followed by a temperature word, TXXX; a dewpoint word, HXXX; a wind direction and speed word, WXX/XX; a pressure word, PXXX; a precipitation word, QXXX; etc. For example, a typical response might be:

ID T081H-09W27/15P952Z012

This response is interpreted as follows:

Station	AB
Temp	081°F
Dewpoint	-09°F
Wind direction	270°
Wind speed	15 kts
Barom. Press	29.52 in. Hg
Cum. Ppn.	012 in.

Clearly, at the rate of 100 wpm, the response would take less than 20 seconds.

The electronics package and teletypewriter terminal requires a small protective building at the remote site.

3.4.2 Sensors

The sensors associated with the remote stations of AMOS are all standard weather service devices. Table III indicates the parameters measured by the various sensors and the accuracy of each.

3.4.3 AMOS Reliability Estimates and Costs

The AMOS electronics package has proven to be particularly trouble free. According to a weather service spokesman, the electronics modules have required repairs only twice during the entire 4-year period the stations have been operational. Thus the 6-month operational probability would exceed 0.95. Inasmuch as AMOS is not subject to the vagaries of radio communications links and battery power, only the

TABLE III-III

ACCURACY AND OPERATING RANGE OF AMOS SENSORS

<u>PARAMETER</u>	<u>ACCURACY</u>	<u>OPERATING RANGE</u>
Wind Direction	10 deg.	0 to 360 deg.
Wind Speed	<u>+2</u> kts or 5%	0 to 125 kts
Temperature	<u>+0.75</u> °F	-58 to 120°F
Dew Point	<u>+0.75</u> °F	30 to 86°F
Baro. Press (Surf.)	<u>+0.03</u> in Hg	19 to 31.5 in Hg
Cumulative Ppn.	<u>+0.02</u> in.	0 to 9.99 in/6 hr
Peak Wind	N.A.	N.A.
Visibility Index	N.A.	N.A.
Manual Input	----	----

TABLE IV

OPERATIONAL PROBABILITY ESTIMATES OF WEATHER

SERVICE SYSTEMS AMOS AND (PROPOSED) RAMOS

NO. OF <u>SENSORS</u>	6-MONTH PROB.	
	<u>AMOS</u>	<u>RAMOS</u>
2	0.56	0.152
5	0.24	0.064
9	0.075	0.020
13	0.024	0.006

sensors limit the reliability of the system to any great extent. Their 6-month operational probabilities are estimated to be 0.75. Thus the overall probability in a system of n sensors would be approximately:

$$P = (0.75)^n$$

The RAMOS system presently being developed will extend the AMOS concept to include radio and satellite communications links where required. Some idea of the way in which provisions limit the reliability of the system can be obtained by comparing the two systems, which are, but for the communications and provisions for on-site power generation, quite similar.

A tabular comparison is shown in Table IV.

For a typical configuration of five sensors, one finds the reliability of the entire system degraded by nearly a factor of 4 in RAMOS because of the radio and absence of commercial power.

According to a spokesman, cost of the AMOS remote stations was about \$7000, including sensors. The weather service anticipates that RAMOS will cost about \$11,600 per station for lots of 10 to 20 production units.

3.4.4 AMOS Critical Review

The inaccessibility of remote sites of value to the Forest Service in its proposed Fire Danger Rating System, particularly in the mountainous western regions, is likely to preclude any notions of commercial power and common-carrier communication links. If we can assume that the quality and reliability of the sensors are approximately equivalent in the AMOS and Forest Service systems, the AMOS electronics package emerges as the single component of interest. It combines sophistication in data processing with proven reliability and notification of parity errors when they occur.

In its present form, the 19" x 8 3/4" panel mount is a bit larger than convenient, unless a building is provided at the remote site. The cost might also be prohibitive. While no cost breakdown was available, we can deduce the approximate cost of the electronics package by subtracting from the station cost the approximate cost of the sensors. Hence \$7000 - \$3000 = \$4000, less radio, antenna, and means of on-site power generation. If we add the costs of these items to the costs of the electronics package, the price of the remote station would be about \$6000.

3.5 General Findings and Conclusions Obtained from Studies of Existing Remote Weather Stations

General Conclusions

1. No existing station is presently operating at a level of reliability, cost effectiveness, and accuracy that would be required for the NFDDS.
2. Failure to meet operational requirements for various systems have been identified. Acceptable engineering solutions to reach the required state-of-the-art are feasible, and given a relatively modest program of development a high probability exists that equipment suitable for the NFDDS can be developed.
3. Cost reduction will in the main be determined by improvements and price reductions in sensors since these devices constitute the greater fraction of total cost.
4. Solid state devices must be used at all possible places to improve reliability.
5. Present system problems could have been reduced if the contracts would have specified a continuing working relationship between the equipment supplier and Forest Service personnel.
6. Base station control with a mini-computer appears extremely attractive due to their flexibility, versatility, and low cost.
7. The use of a mini-computer at the base station would reduce the cost of the electronics at the remote sites. The trade-off of cost of an inexpensive computer at a single site versus the costs of say ten electronics packages at remote sites appears strongly weighted toward the computer. Therefore a dedicated computer is required at the base station.

Specific Conclusions

Sensors

1. Sensors are too expensive and need further development in accord with carefully determined NFDRS requirements.
2. Sensor reliability needs considerable improvement.
3. Present sensors are too large, and cumbersome.

4. Fuel moisture analogs are considerably less well developed and need further testing than any other sensor.
5. Power requirements of the wind speed sensor need to be greatly reduced, and this should be possible.

Power Supply

1. Present power systems for remote sites are marginal.
2. Thermoelectric type generators function reliably, but supply marginal power at rather high cost.
3. Present lead-acid batteries provide less power than expected.

Electronics Package

1. Multiplexers must be designed to eliminate large or long switching transients.
2. Multiplexers must incorporate channels for the following:
 - a. Condition of available power.
 - b. Provide a zero signal check.
 - c. Standardization feature to check accuracy of the system.
 - d. Extra channels for future requirements.
 - e. Emergency communication channel.
3. A/D conversion should be performed at the remote site.
4. If FM modulation signals are used the wave forms must be compatible with the radio selected.

Radios

1. Present radios consume a sizable fraction of total power; however, it is not likely these power requirements will be reduced since radios are a highly developed part of the system.

4.0 REAL-TIME NATIONAL FIRE DANGER DATA SYSTEM

4.1 System Functional Description

The National Fire Danger Data System (NFDDS) is based upon a network concept designed to gather a wide variety of surface meteorological data from an extensive system of sensor stations, consisting of both fire weather stations and flammability sites. Based upon the foregoing examination of existing remote weather stations, the following basic system design requirements are recommended to cover the whole U.S. or other large geographical area.

1. A system composed of four level subsystems of operation. These are:
 - a. National Fire Danger System Headquarters
 - b. Regional Fire Danger Stations
 - c. Base Stations
 - d. Fire Weather or Flammability Sites
2. The complete system must be designed to send command signals and return data utilizing the existing Forest Service communication system.
3. The system must possess a suitable active data storage capability in order that information for one year's fire danger rating-index might be obtained in a retrievable form by both the National Fire System Headquarters and the Regional Fire Danger Stations.
4. The National Fire Danger Headquarters and the Regional Fire Danger Stations must keep a library of printed and EDP data for fire danger data that has been determined to be of suitable importance.
5. The National Fire Danger Headquarters and the Regional Fire Danger Stations must possess sufficient computing capacity to calculate Fire Danger Rating Indexes as required.
6. The function of the base stations will be to interrogate surrounding remote sites, check the data for accuracy, notify the operator of malfunctions, format, and store data as required.
7. Remote sites will consist of two types, Fire Weather sites, and Flammability sites.

8. Remote sites will be designed to operate from 110 V, 60Hz, or from their own power systems.
9. Minimum power consumption will be achieved by careful selection of sensors, multiplexing, and transmission equipment.
10. Integrated circuits will be provided to provide maximum reliability and reduce power consumption.
11. Maximize transportability by minimizing size and weight consistent with other requirements.
12. Modular construction must be provided such that two men can install the NFDDS remote site units, and one man can maintain and repair it.
13. Remote site equipment must be provided that will permit sustained operation unattended for one year in hostile environments. Exposure to all the diverse climatic elements on the north American Continent is assumed.
14. Field repairs will only consist of replacing plug-in modular units to minimize field maintenance down time and to maximize flexibility of system configuration and siting.

4.2 System Functional Specifications

The overall diagram of the NFDS System is provided in Figure II-2. This figure illustrates schematically the following basic system concepts.

1. National Fire Danger Data System consists of four levels specified in Section 2.0, and are interconnected through a command and data linkage.
2. Three communication input-output options will be available to the National Fire Danger System Headquarters, the Regional Fire Danger Stations and the Base Stations. These are leased line, dedicated telephone line, or dial-up telephone line. Detailed specifications for these command links, data handling, storage requirements and characteristics will not be given, except as required to define the Base Station to remote Fire Weather Sites and Flammability sites.
3. The number of regional stations will not exceed 99, and the number of base stations per region will also not exceed 99.

4. The Base Station will have the following command and data transfer capability.

- a. Receive and store data from local surrounding remote sites. Up to five (5) Fire Weather sites and twenty five (25) flammability sites.

The typical Base Station would consist of three (3) Fire Weather sites and fifteen (15) flammability sites. In general the ratio of Fire Weather sites to flammability sites will be one to five (1:5).

- b. Transmit telemetry sensor data to the local Regional Fire Danger Station on a preset pattern or as requested.
 - c. Transmit telemetry sensor data directly to any other Regional Fire Danger Station upon command.
 - d. Transmit telemetry sensor data directly to the National Fire Danger Headquarters upon command.
 - e. Receive fire danger rating index (FDRI) data on a preset pattern or as requested from the local Regional Fire Danger Station.
 - f. Receive FDRI data from other Regional Fire Danger Stations upon command.
 - g. Receive FDRI data from the National Fire Danger Headquarters
5. The National Fire Danger Data System (FDDS) will provide all information in American Standard Code for Information Interchange (ASCII) for all digital data transmission to network levels above the Base Station. This output may be used simply to drive a card or tape punch, a printer, or input to a mini-computer or a time sharing computer system.
 6. The National Fire Danger System Headquarters will probably start with a time sharing computer initially, which may be or may not be switched to a dedicated computer at a later date.
 7. The National Fire Danger Headquarters will be programmed for automatic operation. Operator interrupt and override capability is essential.
 8. The complete system will be designed to operate on a nominal 110V, 60Hz commercial AC electric power except for remote sites which

require their own power supply modules. The 110V supply is specified as 105-130V, 60 $\pm$ 1.0Hz.

9. The highest data frequency for transmission between units will be nominally 3KHz. Voice grade phone lines will be adequate. Radio transmission will be in accord with existing Forest Service standards.
10. All drawings will be in conformance with MIL D 1000 Form 1 and drawn in style MIL STD 100. Wherever possible part numbers and code numbers will be used.

4.3 National Fire Danger Data System Headquarters Sub-System

At the National Headquarters, a dedicated, leased or time shared computer would be available to gather information from Regional Fire Danger Stations. This computer would serve to process information and display it daily in a form that would expedite the making of decisions for the nationwide deployment of fire control resources.

In addition a library would be maintained to store the records of the fire danger data system. Information in this library would be used to detect historical patterns and perfect the broad decision making process.

4.4 Regional Fire Danger Station Sub-System

The U.S. Forest Service operates with a number of Regional Headquarters which serve a large number of functions other than fire control. Therefore, no logical reason presents itself as to why this time tested management and organizational arrangement should be modified simply to utilize a new National Fire Danger Data System. Quite the contrary, the NFDDS must be constructed to serve the present working organization.

The function of the Regional Fire Danger Station will be to receive fire danger data from the base stations under its control in order that this information can be processed into area, forest, and regional Fire Danger Index numbers, transmitted back to controlled base stations, to surrounding Regional Fire Danger Stations, and up to the National Fire Danger System Headquarters. In addition a library of sensor data and reduced Fire Danger Index data will be maintained in an active and backup EDP library.

It is not the purpose of this report to detail all the requirements of the Regional Fire Danger Station Sub-systems but simply to indicate its role in the data communications system to allow a proper and full detailing of the Base Station command and communication linkages. EDP communications systems

at this level are almost standard commodities at this date. Consequently there appears little purpose to be served in merely reciting the existing state of the art.

Given the outputs of standard data formats from base stations it is a simple and easy matter to obtain fixed bids for these higher level data communications systems. There appears no justification for the Forest Service to expend R&D funds for this type activity, as their needs are clearly within the existing state of the art. At such time as the Base Station-Fire Weather Site-Flammability site-sensor use, integration, and reliability problems are worked out to a satisfactory standard, the Regional Fire Danger Station Sub-system complex will be easily procured by standard commercial solicitation on a multi-source basis.

Output Messages from Regional Fire Danger Stations

Sensor Data

The output sensor data output from the Regional Fire Danger Station is formatted in exactly the same way that the output data from the Base stations is communicated.

Fire Danger Ratings

In addition to the sensor data output the FRDS can supply on a regular pre-determined routine or on-demand basis the information supplied by the Local Fire Control Officer and/or the final Fire Components and Fire Indexes.

The identifiers and number of digits for both local fire officer data and the calculated indexes are given in Tables IV-I and IV-II.

The label is exactly the same except that the last two digits are (LO) and (CI) for local fire control officer data and Fire Components and Indexes respectively. The label line is modified by addition of three numbers to describe the geographical area and the sensor station data used in the calculation as follows:

ii (s) ii (s) iii (s) (iii)

Region(s) Base(s) Remote(s) Geographical Location

Message Lengths

TABLE IV-I

LOCAL FIRE CONTROL OFFICER SUPPLIED DATA

	Identifier	No. of Digits
1. Lightning and Man-made Risk	L	2
2. Percent Green	G	2
3. Living Fuel Moisture	H	2
4. Slope Class	I	1
5. Fuel Type	$\frac{R}{5}$	$\frac{1}{8}$
Total Number of Digits per Area		18

TABLE IV-II

FIRE COMPONENTS AND FIRE INDEXES

	Identifier	No. of Digits
1. Ignition Component	IC	3
2. Spread Component	SC	3
3. Energy Release Component	EC	3
4. Occurrence Index	OI	3
5. Burning Index	BI	3
6. Fire Load Index	$\frac{FI}{6}$	$\frac{3}{18}$
Total Number of Digits per Area		36

Communication Times to National Headquarters from Regional Stations

Table IV-III gives the message times per data set from a Regional Station. It is assumed that the RS oversees ten (10) base stations. A greater or lesser number of base stations would require a proportionate time adjustment.

In most instances the National Headquarters would desire information as to the fire Component and Indexes. Other data, except in emergency situations, could be transmitted via mailed magnet tape cassettes.

4.5 Base Station

Description

In the Fire Danger Data System the Base Station is the monitoring and control point that serves a local geographic area which contains a number of remote sites utilizing either Fire Weather or Flammability sensors. The Base Station is the lowest manned sub-system in the NFDDS. Normally it is expected that at this location personnel will be available on a regular business hour basis. During periods of high fire danger the station will be manned around the clock. This requirement however, need not influence the data system since it will be operating in fully automatic mode as required.

The base station should be sited at a local forest station in order to make the results immediately available to those making decisions with respect to fire usage, prevention, suppression, or control. In most cases, it would be located in the same building as the Forest Headquarters transreceiver. The location selection of Base Station is a management decision and will not be discussed in this report.

Environment

The environment of the Base Station is assumed to be that of a typical office. The temperature will be controlled with heating and air conditioning presently available or readily available. Temperatures of 70°F +5°F are assumed. Humidity may not presently be controlled but should be installed to increase the operating reliability of data system hardware.

It is assumed that adequate amounts of 110V (nominal) 60Hz electric power, plus telephones, and/or leased wire terminations are already present. It is further assumed that a VHF Forest Service transceiver and relay system is already available.

The space required for all equipment and operations will be one 100 to 150 square foot office.

TABLE IV-III COMMUNICATION TIMES TO NATIONAL HEADQUARTERS FROM A
REGIONAL STATION HAVING TEN BASE STATIONS PER DATA SET INQUIRE

	Minimum ⁽¹⁾	Average ⁽¹⁾	Maximum ⁽¹⁾
Sensor Readings	40 sec.	100 sec.	180 sec.
Local Fire Control Data	10	30	50
Fire Components and Indexes	<u>20</u>	<u>60</u>	<u>20</u>
Total	90	190	230

Equipment

The following sections will detail the type, function, and operation of the various pieces of equipment to be used. Major pieces will include:

Teletype Unit

Mini-Computer

Transceiver

Telephone lines termination

Leased lines termination

Control Unit - Mini Computer

There are essentially four possible types of control units that should be considered for Base Station data acquisition, processing, communications command and control. These are:

1. Manual systems
2. Mechanical program systems
3. Controllers
4. Mini-Computers

Manual systems require a large amount of operator effort. The incurred cost plus the high probability of human error makes this system so expensive and error prone as to be unworthy of further consideration.

Mechanical control and program systems also present cost, reliability, and flexibility difficulties such that I see little point in considering these systems further. The present mechanical relay system used by the Forest Service fully illuminate and demonstrate these problems, as reviewed in the prior section of this report, so as to eliminate these systems from further consideration here.

A series of devices that make use of modern solid state digital technology for data acquisition has become available within the last two years. These devices effectively monitor a number of data sources, adjust process variables, or ring alarms. The price of these units varies from \$1,500.00 to \$5,000.00.

To an appreciable extent these controllers are customized units particularly adapted to specialized functions. These units have been considered but based upon our best engineering judgment these units will be less useful, less flexible, and more expensive to maintain over a period of years. It is obvious these units can not be competitive with mini-computers.

Mini-computers are currently being produced in such large and increasing numbers that the price is decreasing at a rate of 15 to 25% per year. It is expected that this price decrease rate will continue for several years. As an example the PDP-8/E, 4,000 word, 12 bit computer sold for \$15,000.00 in 1965, \$10,000.00 in 1968, \$8,000 in 1970, and is currently priced for about \$3,500.00 in large OEM quantities. It is a reasonable expectation that by 1975, at which date the Forest Service will be ready for large field deployment of base stations, that the quantity price will not exceed \$2,500.00 and probably will be less. This particular computer possesses the general architecture, and is supported by extensive software programming. The PDP-8/E is cited not as an extreme case, but as the typical computer, since it is produced in the largest volume of any individual mini-computer.

Mini-computers are not only inexpensive but possess the following advantages for the largest volume produced machines.

1. MTBF of approximately 10,000 hours.
2. Flexibility of programming allows different numbers of sensors, remote stations, communication sequences, error checking procedures and use patterns to be altered simply and economically.
3. The capacity of computing power needed by the Base Station for the Forest Fire Danger Data System is sufficiently small that additional usage at the base station should be evaluated.
4. Expandable capacity without hardware modification is an important virtue of the mini-computer. Additions of core memory in units of 4K up to 32K are inexpensive as are installations of bulk memory magnetic tape units of a wide range of capacities and capabilities.
5. Mini-computers are capable of providing appropriate timing and interrogation signals and decoding digital transmissions on a priority basis. This allows for a standardized procedure of higher level communications.
6. Versatility of data display is achieved only by software modifications.

The mini-computer control unit would accomplish the following tasks.

1. Command and interrogate remote sites on either a programmed basis or upon base station operator request, Regional Fire Danger Station request or on demand by the National Fire Danger system Headquarters. Automatic interrogation once per day, as selected by the operator.
2. Receive, decode, error check and correct all sensor data. Hard-copy provided upon operator request.
3. Format sensor data sequences. Providing remote site number, time, date, etc.
4. Store sensor data for a predetermined period of time.
5. Display sensor data with programmed automatic printout, or upon operator command.
6. Transmit to the Regional Fire Danger Station data upon a regular basis. Normally once per day or upon request.
7. Receive, and display, and store the computed Fire Danger Index from the Regional Fire Danger Data station.
8. Serve the diverse needs of the Base Station Forest Service stall for normal computing needs, such as engineering, estimation, etc.

Communications Unit

The development of input/output (I/O) devices have not kept abreast of computers either in terms of cost reductions or operational reliability. Nevertheless an (I/O) device is required at the Base Station. At present the best compromise between cost and reliability would appear to be the ASR-33 Tele-type unit or its equal. The ASR-33 is equipped with a paper tape punch and reader which would allow the following tasks to be performed:

1. Insertion of New Programs
2. Operator entry of instructions via the keyboard.
3. Hardcopy printout of data.

The cost of the ASR-33 is approximately \$1,500.00. This price is relatively stable with inflation slightly more than offsetting the production economies. However, the reliability of the ASR-33 is not fully satisfactory as the MTBF is about four months on the average.

Proper maintenance does help reduce unexpected down time to a certain degree, but at best the MTBF will not exceed six (6) months. There are two ways to reduce the problem. First units can be switched off when not needed, this should extend the MTBF to the one year goal, depending of course upon the amount of use. Secondly, for stations at which repair service is not quickly available, a second spare (I/O) would be kept available. The cost of spare equipment doubles the capital cost, but a survey of (I/O) equipment indicates that this approach is still less expensive than buying a piece of equipment having the reliability of two ASR-33's.

A special operator's console can be designed, but, generally speaking, with the cost of specialized control panels is prohibitive unless they are used in large quantities, (pocket calculators) or for unique applications. The repair and servicing of specialized control panels is difficult, time consuming, and expensive. The ASR-33 unit is almost a standard piece of equipment. They are used in great numbers all over the United States. An independently trained and experienced repair service exists which could not be duplicated on a cost effectiveness basis for special panels. A few maintenance and repair personnel could be trained to cover regional areas, but the cost of travel time and expense makes this clearly uneconomical. Furthermore, the Forest Service has extensive experience and capability in servicing the ASR-33 units, or similar equipment.

Output Message of Sensor Data

The base station output message will be an electrical signal in ASCII serial by bit, and serial by character at a rate of 110 Baud. The signal strength should be sufficient strength to drive the equivalent of two (2) Model 33 teletype printers over a hundred feet of cable.

The format of the output message is recommended as follows:

Label: ii(S) ii(S) dd(S) yy(S) tttt(S) (SD)

Message: ii(S) iii(S) D(S) ZXXX(S) CXXX(S) BXXX

.
.
.

ii(S) iii(S) QXXX(S) EXXX(S) YXXX

(S) Indicates Space

X Indicates numerical digit when following a parameter identifier letter
(or minus sign).

(SD) - Sensor Data

ii(S) ii(S) in label is the four digit designation for the base station: the first two positions indicate the Regional Fire Danger Station, and the second (ii) indicates the Base Station number. The Base Station Number is used again as the first two positions followed by (iii) which indicates the remote site identification. The first letter is a (J) or a (K) and indicates either a Fire Weather Site (J), or a Flammability Site (K).

The (dd) portion indicates the day (01) to (31), (yy) indicates the last two digits of the year, and (ttt) indicates the time in hours and minutes from 0000 to 2359 in local time.

The remainder of the message contains a series of identifier letters and digital data. Table IV-IV gives the codes and the number of digits per code for both types of remote sites.

Missing environmental parametric information may be indicated by printing the appropriate number of SLANTS (///) for the missing data. If a remote site fails to respond to a call-up from the Base Station, the output message will give the Remote Station Identification and print out "NO RESPONSE" for the message.

All identifier letters and their meaning are given in Table IV-V.

The times of transmission of messages from and to the Base Station (Regional Headquarters) are given in Table IV-VI. At the most only about 1/4 minute is used to transmit the data back and forth per inquiry. No time has been allowed for the computations. Message times per inquiry do not appear excessive in terms of either time or cost.

4.6 Remote Sites

Description of Fire Weather and Flammability Sites

Remote sites surround a base station in a given but variable sized general geographical area. They are designed to measure selected meteorological data and related fire danger information. These remote sites are of two types: 1) Fire Weather Sites, and 2) Flammability Sites. The major difference in the sites is the number and type of sensors per site. Remote is used as a word to indicate a site not geographically at the Base Station. A portion of these stations are isolated. Isolation by definition means not supplied by commercial utilities such as commercial electric power or telephone lines.

The environment of these sites will be essentially that of a full exposed outdoor micro-climate at the given location. These remote sites will be deployed over virtually the entire North American Continent and will, consequently, be subject to variable weather and climatic conditions ranging from

TABLE IV-IV FIRE WEATHER AND FLAMMABILITY SITE DIGITAL SENSOR DATA

Data Source	Identifier	No. of Digits
1. Zero Signal	Z	2
2. Standard Signal	C	3
3. Battery Power Condition	B	2
4. Windspeed	W	2
5. Wind Direction	D	2
6. Air Temperature	T	3
7. Air Moisture	M	2
8. Precipitation Amount	A	3
9. Precipitation Duration	U	2
10. Fuel Temperature	F	3
11. Fuel Moisture - 1 hr.	N	3
12. Fuel Moisture - 10 hr.	O	3
13. Fuel Moisture - 100 hr.	P	3
14. Duff Moisture	Q	3
15. Emergency Line	E	2
16. Spare Circuit	<u>Y</u>	<u>3</u>
Totals	16	41

Plus 16 Spaces

Total Digits Per Site Required Fire Weather - 73

Total Digits Per Site Required Flammability - 64

TABLE IV-V IDENTIFIER CODE LETTER AND DATA REPRESENTED

Identifier	Data
A	Precipitation Amount
B	Battery Power Condition
C	Standard Signal
D	Wind Direction
E	Emergency Channel
F	Fuel Temperature
G	Percent Green
H	Living Fuel Moisture
I	Slope Class
J	Fire Weather Site
K	Flammability Site
L	Lightning and Man-made Risk
M	Air Moisture
N	Fuel Moisture 1 Hr.
O	Fuel Moisture 10 Hr.
P	Fuel Moisture 100 Hr.
Q	Duff Moisture
R	Fuel Type
S	Space in Message Layout
T	Air Temperature

TABLE IV-V (Continued)

U	Precipitation Duration
V	
W	Windspeed
X	Indicates Data Digit
Y	Space Circuit
Z	Zero Signal
BI	Burning Index
EC	Energy Release Component
FI	Fire Load Index
IC	Ignition Component
OI	Occurrence Index
SC	Spread Component

TABLE IV-VI COMMUNICATION TIMES OF
FROM AND TO BASE STATIONS⁽⁵⁾ PER DATA SET

	¹ Minimum	² Average	³ Maximum
Sensor Data - From B.S.	4 sec.	10 sec.	18 sec.
Local Fire Control Data - B.S.	1 sec.	3 sec.	5 sec.
(4)Fire Components - From Regional	2 sec.	6 sec.	10 sec.
Total	9 sec.	19 sec.	23 sec.

1. Assume 5 Flammability Sites, plus 1 Fire Weather Station Sites.
2. Assume 15 Flammability Sites, plus 3 Fire Weather Station Sites.
3. Assume 25 Flammability Sites, plus 5 Fire Weather Station Sites.
4. Assume three geographic localaties per site.
5. Assume 110 Baud rate.

Artic to Tropical. Environment is understood to include exposure to all types of rodents, insects, and animals as well as the elements.

At the Fire Weather site the following components are required:

Meteorological Sensors	A/D Conversion
Fire Danger Sensors	Multiplexing Unit
Power Supply	Communications Link

The functions of these components will be:

- Sense the desired information.
- Convert analog information to digital.
- Transmit the digital data upon command
- Provide a self contained power sub-system (as needed).

Fundamental considerations for the design of the Fire Weather Site equipment includes:

- Severe and variable environmental conditions at open areas exposed to the wide variety of weather conditions that exist over the U.S.
- Maximum reliability of all electronics to reduce maintenance costs. The five year goal should be semi-annual inspection and maintenance. All electronics should be solid state devices. A ten year goal of one year mean time to failure MTTF.
- Power consumption at the Fire Weather Sites must be kept to a minimum. The cost of an inspection or battery replacement trip is so high that cost effectiveness requires an overdesign by all conventional power supply standards. Duplex battery storage must be considered and alternate battery charging systems are probably essential.
- The weight and size of the FWS and FS components must be kept to a minimum while still maintaining the required reliability and cost considerations. All components must consist of sealed special weather proof cases with rapid tight external connectors to provide for all circuit connections. Installation must be accomplished by two men in a period of two to three days.
- Field trouble shooting will not consist of any adjustments in the field. When a component failure occurs a plug-in sealed replacement substitution will be made for the defective unit. All connectors must be selected or designed so that changes can be made at temperatures to 40°F and snow, or up to 120°F, rain and 100% RH. The units must be so designed that a completely inexperienced person can substitute components without the possibility of error: that is, all connectors must be color coded and unique. Connectors must be designed to be handled with gloves or mittens.

- f. Remote sites must be designed to send three calibration signals.
 1. Condition of power supply.
 2. Zero signal.
 3. Standard calibration signal.

Fire Weather Sites

A Fire Weather Site consists of a collection of twelve (12) sensors, plus four (4) channels devoted to functional and emergency information, and two spare channels. Additional channels up to twenty four (24) total should be added by inserting more plug-in cards. Table IV-VII gives the types of sensors and the number for each remote site.

Flammability Sites

A Flammability Site consists of six sensors/ four fuel moisture analogs, plus fuel temperature, and windspeed. Approximately five flammability sites will be deployed for each Fire Weather Site. Table IV-VIII gives the types of sensors and the number for each flammability site.

Sensors

No discussion of the types, nature, construction, source of errors or limitations of the various meteorological or other sensors will be given at this time, since the purpose of this report is to review the systems features required to collect remote data. Only information of relevance at this time will be discussed: namely, the range and accuracy required of each sensor. This data given in Tables IV-IX and IV-X directly determines the number of data digits required to transmit the data in digital form.

Interfacing the various sensors requires an electronic amplifier in the electronic package capable of operating over a wide range of input signals. Devices of this type are available and are described as a part of the electronics package.

A/D Unit

The remote site electronics will include an analog to digital conversion system capable of accepting signals from all the different sensors and transmitting them as digital pulses.

For example, one way that this conversion might be accomplished is shown in Figure IV-1. The signal from the sensor is carried through an

TABLE IV-VII FIRE WEATHER SITES - NUMBER OF SENSORS PER STATION

Data	No. of Sensors
1. Fuel Moisture Analogs	4
2. Fuel Temperature	1
3. Windspeed	1
4. Wind Direction	1
5. Air Temperature	1
6. Relative Humidity	1
7. Cumulative Precipitation - 24 Hr.	1
8. Length of Rainfall	1
9. Soil Temperature	<u>1</u>
	12
Other Data	
11. Power Supply Condition	1
12. System Zero Signal	1
13. System Calibration	1
14. Emergency Channel	1
15. Spare Sensors	<u>2</u>
(1) Total Sensors	18

(1) Expandable by card insertion to 24 channels

TABLE IV-VIII FLAMMABILITY SITES - NUMBER OF SENSORS PER STATION

Sensors	Number of Sensors
1. Fuel Moisture Analog	4
2. Fuel Temperature	1
3. Integrated Windspeed (1 hr.)	<u>1</u>
Total	6

Other Data	
4. Power Supply Condition	1
5. System Zero Signal	1
6. System Calibration Signal	1
7. Emergency Channel	1
8. Spare Sensors	<u>2</u>
(1)Total Sensors	12

(1)Expandable by card insertion to 24 channels.

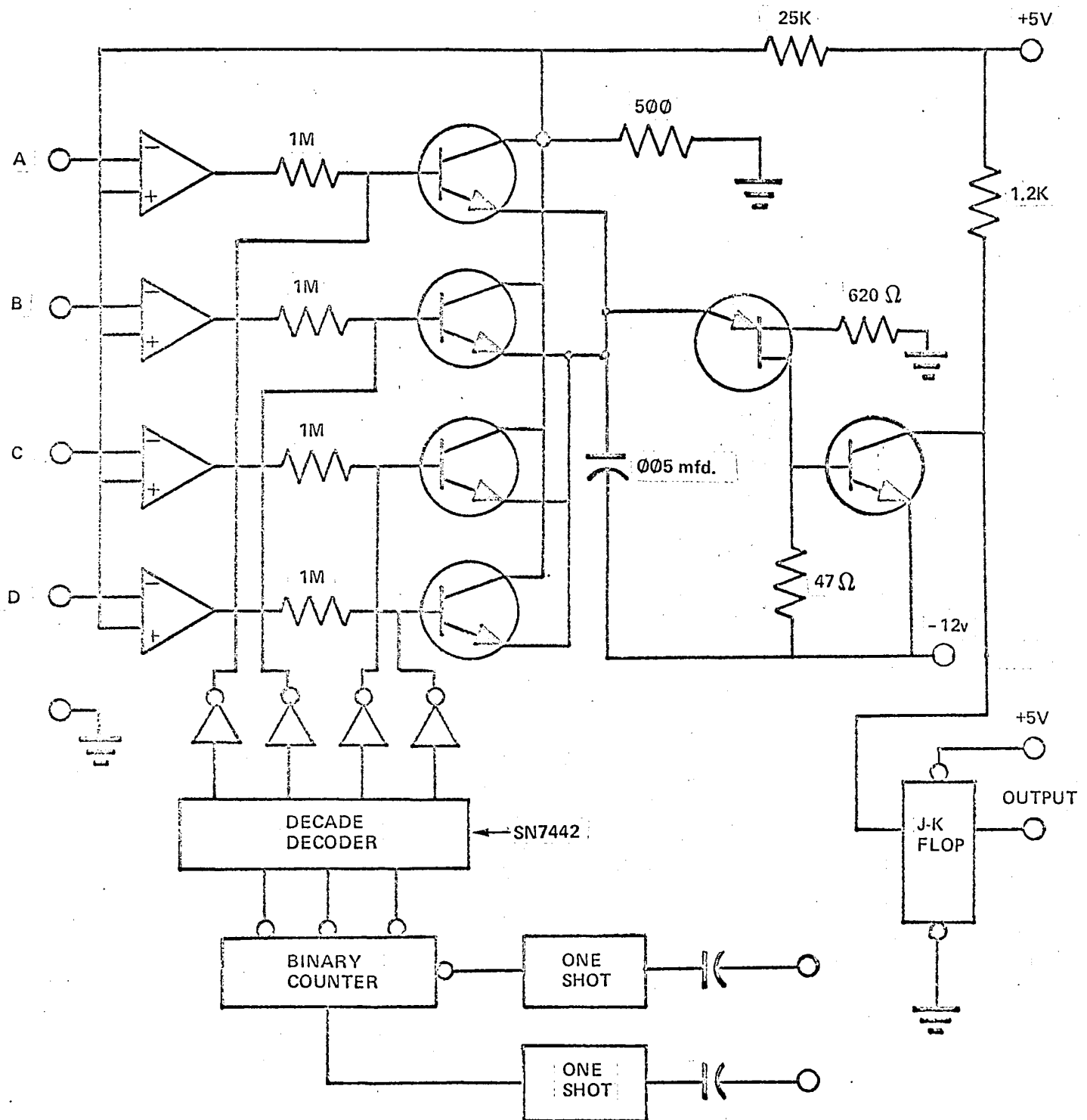
TABLE IV-IX FLAMMABILITY SITE SENSORS AND DATA QUALITY

Sensor	Accuracy	Operating Range
Windspeed	1 Mph	0-99 Mph
Fuel Temperature	1°F	0-160°F
Fuel Moisture TL-FM-1 Hr.	0.1%	1-30%
Fuel Moisture TL-FM-10 Hr.	0.1%	1-30%
Fuel Moisture TL-FM-100 Hr.	0.1%	1-30%
Duff Moisture	0.1%	1-30%

TABLE IV-X FIRE WEATHER SITE SENSORS AND DATA QUALITY

Sensor	Accuracy (+)	Operating Range
Windspeed	1 Mph	0-99 Mph
Wind Direction	10°	0-359°
Air Temperature	1°F	0-120°F
Air Moisture (RH)	3% (52-95%)	1-100%
Precipitation Amount	0.02 in.	0-9.99 in.
Precipitation Duration	1 Hr.	0-24 Hrs.
Fuel Temperature	1°F	0-160°F
Fuel Moisture TL-FM-1 Hr.	0.1%	1-30%
Fuel Moisture TL-FM-10 Hr.	0.1%	1-30%
Fuel Moisture TL-FM-100 Hr.	0.1%	1-30%
Duff Moisture	0.1%	1-30%

FIGURE IV-1 REMOTE SITE ELECTRONICS



TRANSISTORS ARE 2N5172

operational amplifier to a voltage controlled oscillator (VCO) and then to the central station mini-computer. The frequency of the square wave pulses depends, generally linearly, upon the analog signal level created by the sensors as adjusted by their respective operational amplifiers.

Other fully digital data units for remote sites must be considered. The decrease in price of logic chips is continuing, and has reached a level such that a small complete digital A/D conversion at an acceptable price may be possible within the next five, certainly ten years.

Multiplexer

A multiplexer unit capable of scanning upon command the various sensor voltage outputs, as conditioned by an operational amplifier, is required to transfer data to the base station. One suggested possibility is shown in Figure IV-2. The command signals consist of a series of pulses. First a negative pulse resets the multiplexer and the following positive pulses provide a sequence command to transfer from analog to analog.

Radios Links

Commercial FM radios used by the Forest Service are well designed, rugged, and highly developed. It is not expected that this equipment will become obsolete or dramatically improved in the foreseeable future. It would be desirable to reduce the electric power used to transmit a particular distance. However, the desired reduction in power requirements is more likely to be achieved through the use of directional antennas than by radio redesign.

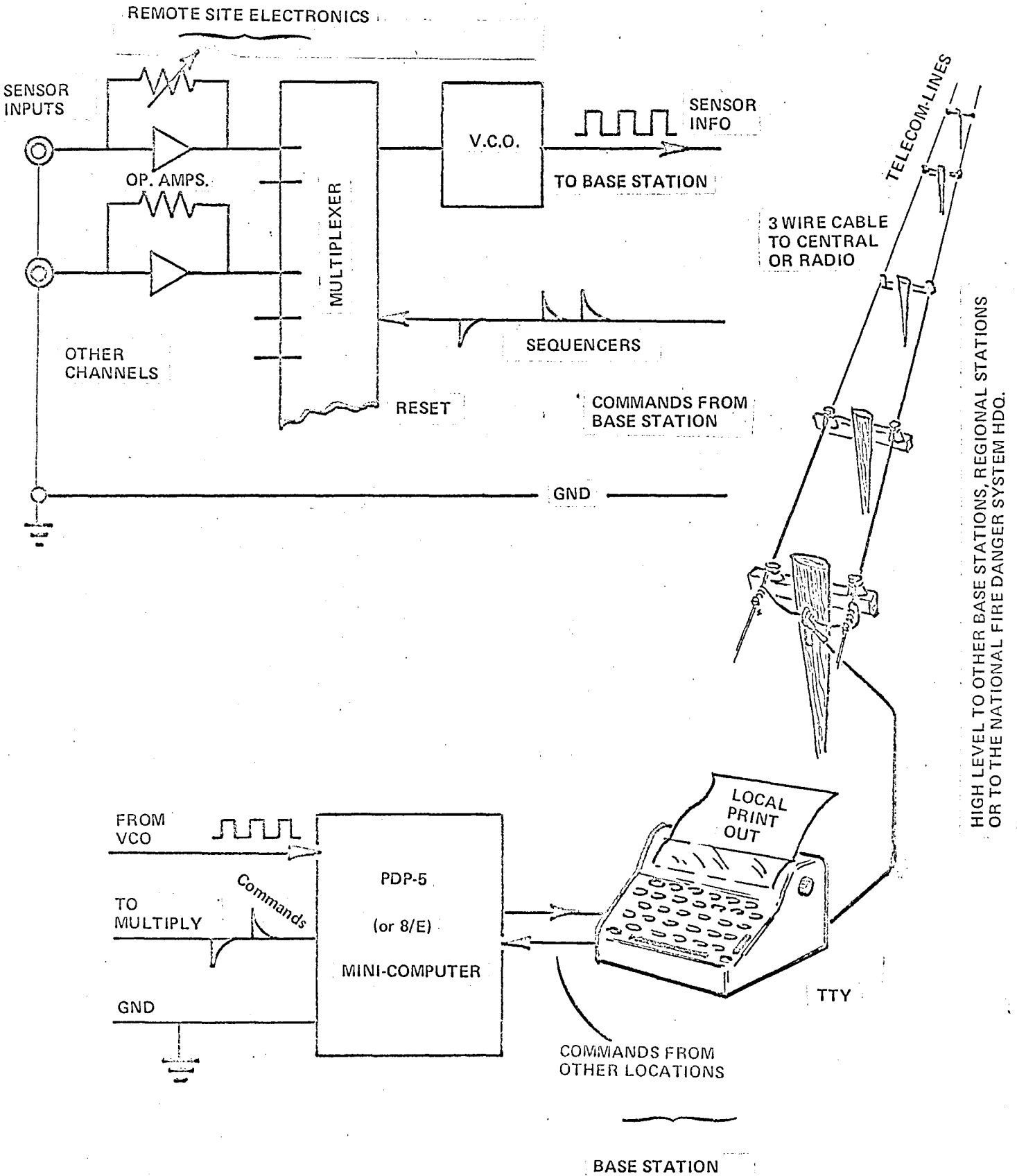
Obvious design considerations must be followed, such as common polarity for ground (negative or positive) for both the radio and electronics package. Also, the digital information created by the analog to digital conversion system must be conditioned to properly modulate the transmitter.

The present Forest Service radios are probably adequate for most purposes.

A Base Station Command interrogation of its remote sites via a command link utilizing existing Forest Service VHF voice radio frequencies is recommended. Both command instructions and data transmission take place in relatively short time. Normally the Base Station interrogates remote sites at programmed intervals. These intervals will be altered as needed by a simple teletype instruction to the control mini-computer. In addition, special command instructions can also be given as required.

Each remote station is interrogated in a standard roll call sequence. Command instructions will be given via a unique address most likely by a

FIGURE IV-2 MULTIPLEXER AND OSCILLATOR



given tone combination. The base station will monitor the channel and when the channel is vacant for a selected time, possibly 2-5 seconds, a warning tone will be given to voice traffic, and then command instructions will start.

Table IV-XI gives transmission times required by two different computers, the PDP-5, and the PDP-8. The shortest possible time for transmission time of digital data in frequency form is 333 milliseconds, i.e., the time required to accumulate 1,000 counts. If the remote station responds with valid data the next station on the roll call is interrogated until all stations are received.

As each remote site is polled, and if no data is received, the computer repeats the command three times. If no response is received the station is listed as completely out of order on the print out to notify the operator. The operator may then attempt to interrogate the non-responsive remote site manually. Normally the operator will verbally request users to refrain from voice communication for a limited time in order to clear the channel.

Channel noise levels are detected and separated by means of two error transmissions. First, a zero signal is given by each remote site. Second, a standard signal is given of a specified frequency. Using both the error signal and the standard frequency, the control mini-computer can detect error noise and eliminate the incoming noise in the analog signals. Should noise exceed a predetermined level, then the operator will be notified after the third interrogation.

The interrogation signal will turn ON the site transmitter and at the close of each request turn OFF the transmitter to conserve power. In a similar manner any sensor requiring excessive power can be switched ON and OFF. The receiver section of the radio will operate continuously.

Each site will be provided with an antenna. An antenna gain of 10 db will provide a factor of ten increase in radiated power in a selected direction.

Alternate Communication Links

For remote sites that can be hard wired, the options of leased lines, telephone circuit, or dial-up phone communications are preferred. When phone lines are used, the remote station will provide the MODE N function, and the line release for dial-up facilities.

All command and data transmission functions and capabilities will be the same as described under the proceeding radio link section.

Power Requirements

All remote sites will be provided with either: 1) A 110 V 60Hz nominal voltage power supply and a backup battery supply for ten (10) days, or 2) A self-contained thirty day battery system plus an independent generation system.

TABLE IV-XI BASE STATION, NUMBER OF FIRE-WEATHER AND FLAMMABILITY SITES REPORTING AND THE TRANSMISSION TIMES FOR TWO DIFFERENT COMPUTERS

1. Base Station - Number of Remote Stations

Remote Sites	Min.		Typical		Max.	
	No.	Sensors	No.	Sensors	No.	Sensors
Fire-Weather	1	12	3	36	5	60
Flammability	<u>5</u>	<u>30</u>	<u>15</u>	<u>90</u>	<u>25</u>	<u>150</u>
Total	6	42	18	126	30	210

2. *Transmission Times (Seconds) PDP-5

Remote Sites	Min.	Typical	Max.
Fire Weather	16 sec.	48 sec.	80 sec.
Flammability	<u>55 sec.</u>	<u>165 sec.</u>	<u>275 sec.</u>
	71 sec.	213 sec.	355 sec.
Approximately:	1.1 Min.	3.5 Min.	6.0 Min.

*Assumes 800 Milliseconds per sensor plus command interrogation time.

3. **Transmission Times (Seconds) PDP-8

Remote Sites	Min.	Typical	Max.
Fire Weather	6.0 sec.	18.0	30.0
Flammability	<u>15.0 sec.</u>	<u>45.0</u>	<u>75.0</u>
	21.0 sec.	63.0	105.0 sec.
Approximately:	1/3 Min	1 Min	1 1/2 Min

**Assume 333 Milliseconds per sensor

Type 1 power supply is to be used for those sites available across the United States where commercial power is available. The ten day back-up power supply is recommended, because, in our judgment, commercial utility systems will suffer a marked deterioration in reliability. The ten day back-up supply may be inadequate in remote areas throughout the west in locations where heavy snow falls or winds may interrupt power service. This is especially true of those areas in which snow fall data is collected as a secondary part of the meteorological data.

Our studies have identified the anemometers and the radio transceivers as being the primary sources of power consumption. The receivers must operate continuously and require several watts. Little can be done about this requirement. The input power of the transmitters is about 135 watts, but they operate only for about 36 seconds each 5 hours at present in the Shoshone Station, so that the average power is only about 0.27 Watt. The anemometers require about 0.42 Watt on a continuous basis. The remaining sensors and the electronics package require almost negligible power by comparison.

In the proposed National Fire Danger Data System more frequent sampling would be required; such sampling would increase the average power of the transmitter in proportion to increased transmission time. Table IV-XII shows typical average power requirements for various sampling intervals.

Clearly, more frequent sampling will increase the average power consumed by the station. The present 9-watt thermo electric generators presently in use will be inadequate, particularly when the efficiency of the DC-DC converters is taken into account. Whereas the thermoelectric generators being used presently offer high reliability, the smaller units (9 watts) are not capable of supplying power in the desired quantity, and even the smaller units are almost prohibitively expensive for national deployment, as would be solar panels. The cost for either system would be approximately \$75 per watt.

Wind driven generators have received considerable attention recently as alternate, clean, and inexpensive, if somewhat unconventional sources of energy. Huge windmills were built as early as 1931 for commercial generation of power. Interest continued into the 1940's, but the machines were never entirely successful, suffering from low efficiency, excessive weight and mechanical complexity. Recent interest has been due to concern over pollution, and to technological breakthroughs in aerodynamics and materials science, which make light weight, efficient, low speed airfoils possible. Modern large-scale generators have been designed and built at Princeton University, the University of Oklahoma, and the University of Massachusetts.

Meyer⁽¹⁾ has recently developed a small wind driven generator featuring a 3-blade rotor having a diameter of 10 feet. The blades use a Wortman FX

TABLE IV-XII POWER REQUIREMENTS FOR REMOTE STATIONS

*AVG POWER FOR SAMPLING INTERVAL (WATTS)

COMPONENT	<u>4 HR</u>	<u>1 HR</u>	<u>15 MIN</u>
Receiver	2.5	2.5	2.5
Anemometer	0.42	0.42	0.42
<u>Transmitter</u>	<u>0.68</u>	<u>2.70</u>	<u>10.8</u>
Stations Totals	3.60	5.62	13.72

*Based on typical station total response time of 72 seconds.

60-126 airfoil, and are made by expanded-paper honeycomb covered with fiberglass. The blades turn at 110 to 115 rpm in a 10-12 mph wind, turning an automobile alternator at about 1000 rpm through a chain drive. Total weight of the device, including its 12-foot tower is less than 300 lb. and it probably could be produced commercially for about \$500. Power generated by the machine is a function of wind speed of course, and the blades are designed for maximum efficiency at a windspeed of 10 mph. Output power varies from 187 W at 10 mph to 4476 W at 30 mph.

Clearly, this wind-powered generator could provide a minimum of ten times as much power at 10 mph windspeed as is presently produced by thermoelectric generators in the Shoshone system. Such capacity would doubtless be desirable as sampling frequency is increased. Moreover, a wind driven generator at the remote sites would eliminate the necessity for fuel, and would thus cut initial cost considerably, perhaps below that of the present thermoelectric generators. Since remote site power is so critical in the Forest Service scheme, we suggest that further study of the wind-driven generator concept. Such devices could produce all the necessary power, and could be appropriately calibrated to serve as wind speed and wind direction sensors as well.

The primary electric source will be wind generators charging storage batteries combined with thermoelectric generators as back-up units in order that power would be available during period of extended calm.

Final selection of the preferred electrical generation method to supply the battery system of the various options (e.g. wind generator, solar cell, or thermoelectric) will be based upon further engineering analysis and evaluation. It must be recognized that since solar intensity, and wind velocities vary greatly from location to location there is no single best choice. For those few sites where both wind and sun power are marginal, a backup thermoelectric generator would be required. Therefore, it seems desirable that a plug-in arrangement should be made to allow for the selected operation of more than a single type of generator.

Remote Site Shelter or Burial

A key design option is the question of protecting, to a reasonable extent, the electronics package: batteries, transceiver, A/D converter, multiplexer, and parts of the power generator. This might be accomplished by housing these units in a shelter structure, requiring prepackaged surface containers, or burial containers.

Ideally the remote shelter for batteries and electronics should be kept dry and at as close to room temperature as possible. Batteries in operating systems have given difficulties due to their inability to deliver the power

outputs required, even though these were well within the specified performance.

A reinforced fiberglass container, well designed and properly insulated, might house the batteries or other vital electronic parts; such a container should be designed for multiple use and capable of simple modification for use in desert heat, swamp moisture, mountain snows, or extreme cold. If a wind driven generator unit is used for charging, surplus power could be diverted to heat the containers to preset and preselected temperatures. Reducing desert heat is a good deal more difficult, and would require the use of thermoelectric cooling units, which are expensive and not too reliable.

Underground burial reduces temperature variations, but increases the possibility of moisture damage. Usually overwet sites can be identified, though melting snow may be present for a period of time during the Spring and Summer. Alternate melting and freezing during day and night are a particularly difficult environmental hazard.

The question of enclosing the electronics in a subcontainer adjacent to the batteries must be considered. The thermal mass of several batteries would reduce the rate of temperature change, and thereby reduce electronic component failures. However, the presence of battery acids may subject the electronics to chemical corrosion.

Environmental hazards are not limited to weather, but also to lightning, snow slides, falling rocks and tree limbs, insect, and animal damage as well as human vandalism. For some of these above ground shelters are desirable to reduce hazards; for others below ground would appear more protective.

It is not possible to make any useful study of design trade-offs for such important and critical questions. The forest service probably has more experience than anyone else in answering questions of this type. However, different approaches should be tried and allow the final decision to be made on field test experience.

There is general agreement that the protection of equipment, particularly cables from all animal damage is very difficult. Buried cables are continually being reformulated, redesigned, and still they fall victim to various insects or rodents.

Installation

Two types of installations are recommended: 1) a shelter situated on a concrete pad, 2) a burial procedure. In the case of isolated sites it may not be possible to pour concrete pads. For these cases a tie down shelter arrangement may be used.

A third additional remote site configuration may be desirable for initial testing of systems and for later use in areas that are of critical interest at a particular time. This would be a mobile van unit, or perhaps a helicopter carry-in Fire Weather Site or a Flammability Site.

Transportation will normally be by truck but for the isolated areas special all terrain vehicles, horses, or even backpack may be required. It is also expected that helicopters will come into increasing forest service use. Before final remote design is selected, a review of the configuration recommended herein should be considered in the light of Forest Service plans to purchase helicopters. These aircraft when not employed in fire suppression very well might be efficiently used in setting up isolated sites.

Remote sites shall be designed in such a manner so as to allow installation and activation by no more than two (2) electronic technicians. Therefore, no component of the remote site equipment shall weigh over 100 pounds including shipping container. All shipping containers shall have suitable handles and grips to allow two man portability. For isolated areas the largest unit must not exceed fifty (50) pounds and be configured such that they can be carried by one man on a backpack.

Site preparation cannot be assessed at this time, but interviews with experienced local Forest Service personnel will provide the required information. Site preparation time will be a function of local conditions; such as site accessibility, cover, soil conditions, climate, weather, and the availability of local casual labor, pre-mixed concrete, telephone, and commercial power. At many locations, local construction equipment may be available to reduce manpower needs.

The actual local site requirements for remote sites will vary from place to place and are not easily subject to overall specifications. Site preparation work which significantly alters the forest or local vegetation is undesirable in that it changes the representative data of that locale.

The activation of a site should be performed by a team of two (2) men in a period of four (4) hours, i.e., 8 man hours. This should allow travel time to assure that at least one remote site per day is installed. A standard check-out procedure should be followed to ascertain that the site is fully operational prior to leaving the area.

All shipping containers and packing material must be designed to be removed from the site. Training of electronics technicians and all site preparation labor must include instruction as to litter prevention and environmental protection. Rigid inspection procedures should be practiced for all remote sites.

All exposed hardware, e.g. antenna, electronics packages, power supplies, electrical generators, as well as shelters, must be designed to conform with local Forest Service practice as regards visual impact. Gaudy, shiney or visually objectional materials or surfaces must be avoided. One possible configuration that must be considered would be small erectable geodesic domes. Suitably painted, these structures could provide the area and space required, be of light weight and easily erectable, as well as conforming to the best accepted environmental style.

Before hundreds of stations are erected throughout the National Forests, it is recommended that interested environmental groups be made a part of a citizens advisory group to assist in the planning and design of remote sites. The greatest resistance will be encountered if no prior discussions and communications are held prior to these units springing up all across the landscape.

Shelters may be designed to serve as emergency units for stranded hikers and hunters. Emergency telephone equipment should be considered in remote or isolated areas. The presence of these shelters in remote forest areas will be of most objectionable, but it is in precisely these areas that emergency shelters would be of greatest value. This value would be appreciated by the environmentally orientated people who would be exposed to them.

Controlled access during summer periods may require the installation of an external telephone for emergency calls. A combination lock could be used and the numbers given over the radio for use of the shelter or first aid kit.

Compatability and Reliability

In our survey of existing technology we found that the overall reliability of the remote stations was most seriously limited by the radio transceivers, and except for a few accessible stations which can be hard wired, the radio is a vital component of the station. On the other hand, the operational probability of the electronics package was quite high in two of the systems we studied. Also, while the number of sensors has an important effect on the overall 6-month operational probability the reliability of any single sensor is likely to be at least twice that of the radio. With these thoughts in mind, we recommend the following:

1. The radio should be entirely compatible with the electronics package and power supply. For example, both radio and electronics package should have the same polarity, whether negative or positive ground, in order to facilitate the use of a single power supply for both.
2. Care should be taken to assure that digital information created in the electronics pack is suitably conditioned to properly modulate the radio transmitter.

3. The contractor should be allowed sufficient time to develop solutions to these problems of compatibility, which are unanticipated in most cases.
4. A series of acceptance tests should be conducted before the equipment is installed. The series should specifically include tests for compatibility and operation under expected field conditions.
5. The electronics pack should be designed to accommodate a large number of sensors, but with the provision that it functions with any number less than the maximum.
6. The electronics pack should not be adversely affected by the failure of any single sensor or combination of sensors.
7. The system should be designed for modular construction to permit exchanges of modules in the field, and return of defective modules to the shop.
8. A remote-station test set should be developed to permit relatively unskilled technicians to identify and replace defective modules in the field. The modules should be small and compact, particularly if burial is required, and should be equipped with weather proof plugs or terminals.
9. The electronics pack should include provisions for measuring the condition of the storage batteries, and if a VCO is used, a zero-signal frequency check should be provided. A check of each sensor would be desirable if simplicity and low cost can be preserved, with provision for transmission of an error message in lieu of the data.

Cost Estimates

The cost of the remote stations may vary greatly, depending on the electronics pack used, the power supply, the number and kinds of sensors, and the buildings or shelters required. There are certain fixed costs associated with the remote stations, which would be required in any event. To illustrate consider a remote station with radio data link to the central. Table VI shows the approximate cost of the least expensive existing system (Boise) as compared with a station of design similar to that proposed by MCI.

Apparently, the improved electronics package proposed by MCI could result in a saving of about \$700. The remainder of the difference in the totals is attributed to the generator and the modern sensors. It might be anticipated that further savings would result from lower operational costs which would result from the absence of fuel and lower maintenance. Total savings for the initial investment would be about \$2000.

TABLE IV-XIII

APPROXIMATE COST OF EXISTING AND *PROPOSED REMOTE STATIONS

BOISE		MCI	
ITEM	COST	ITEM	COST
Radio Transceiver	\$ 900	Same	\$ 900
Antenna	150	Same	150
Temp Sensor	600	Same	600
R.H. Sensor	650	Same	650
Cum. Ppn Sensor	550	Same	550
**Thermoelectric Gen.	\$1000	Proposed	500
Anemometer	550	Proposed	50
Wind Direction Sensor	650	Proposed	200
Electronics Pack	<u>1000</u>	Proposed	<u>300</u>
TOTAL	\$6050	TOTAL	\$3900

*Typical cost of components of a system envisioned by MCI

**A hypothetical component. The existing station used dry batteries with no provision for replenishment. Such a system is not compatible with the requirements of the station.

5.0 SUMMARY CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

1. Remote weather stations currently operated by the Forest Service are too expensive and unreliable to serve directly as the equipment for the National Fire Danger Data System.
2. The existing Forest Service remote weather stations have proved to be of great value as test bed units. The Forest Service has gained useful and valuable experience as to the modes of operation, the limitations, and a clear understanding of the problems associated with the enormous environmental demands imposed upon equipment of this type.
3. The existing Forest Service remote weather station limitations and even failures, in our judgment, represent a less expensive learning process than endless "system analysis" studies and engineering effort expended to anticipate and solve all problems in advance. Consequently the purchase, field, trial, and evaluation of the remote stations represents an efficient and close to optimal procedure for making the greatest progress for the least cost in dollars.
4. The present Forest Service remote weather stations and remote site sensors are sufficiently close to acceptable performance that only relatively small changes have a high probability of success are now required in remote weather station equipment.
5. Based upon the present state of the art and recommended small but important modifications, it appears that an economical, reliable, and useful system can be obtained.
6. There is no substitute for actual field trials and hands-on operating experience to perfect the new generation of remote weather station equipment and test its serviceability for the NFDDS.
7. All Forest Service personnel were helpful, candid, and not only expressed a genuine desire, but translated this thought into action to allow a sound valid critical review of equipment that had not always met their expectations. It speaks well of an organization that it is willing to be open and honest in evaluating failures, or partial failures, as an opportunity to reach the desired goal.
8. Forest Service management is to be commended for ordering an open, critical, and demanding review of a subject that could have been viewed merely as a minor embarrassment.

9. Based upon this study and the recommendations contained herein we believe the Forest Service correctly identified the most critical problems in implementing the NFDDS. Further the recommendations of this report will allow continued remote weather station technology at a modest cost.
10. The modifications needed to improve sensor performance, remote site electronics, and Base Station facilities can be funded and supported by existing private firms.
11. The present Forest Service remote Weather Station system are generally failures only in minor, but critical, details. These corrections once made should yield a system that still may be improved in several ways, but will not be subject to gross systems failure.
12. Environmental effects on equipment have not been fully established for all climate types and conditions, nor wildlife, and insects.
13. Remote site equipment will be exposed only to a limited number of people. However, these people will be hikers, backpackers, bird watchers, hunters, skiers and fishermen, and thus will be very concerned about the intrusion of improperly designed equipment into remote areas.
14. Based upon our best technical judgment we think that the base station monitor unit should consist of a mini-computer. The use of FM radio communication lengths, for frequency pulse data transmission, will require considerable but not excessive computer time. It is to be anticipated that within five to ten years a digital data unit capable of handling the multiplexing, A/D conversion, and formatting of data in digital form at the remote sites will be available. As this unit is developed it can be placed directly into the system as a substitute for the FM type units.

5.2 Recommendations

General

1. That no major mass procurement and deployment of Remote Flammability, or Fire Weather site or Base Station equipment be undertaken at this time.
2. That no major R & D activity is required at this time to further develop equipment and components for the National Fire Danger Data System.

3. That the Forest Service commence a limited field test program of three to four years duration. The purpose of this field test program will be to:

Provide private firms with information as to the improvements needed in remote weather station equipment to make it meet the needs of NFDDS.

Allow procurement of at least two (2) and preferably three (3) different remote site and base station facilities.

Field test equipment under a wide range of different environments. Specifically field tests should be undertaken for at least a year in a cold climate, Alaska and Maine; wet humid, Alabama or Florida; cold and wet, Washington or Oregon; and hot and dry such as Arizona or Southern California. In addition one unit should be installed as soon as possible near the vicinity of the group responsible for developing the NFDDS.

Allow Forest Service personnel gain experience in equipment sitting, start-up problems, employee training, maintenance, etc.

Accumulate maintenance records, and actual performance data.

Allow the development and growth of experience in data utilization.

Provide time to develop computer programs that deal with day to day operational system problems.

Give an opportunity to carefully and completely debug programs and operating procedures.

Permit the replacement or modification of system components that do not meet new requirements.

Define system requirements more fully.

Allow an opportunity to study various trade-offs that do not lend themselves to analysis except under operating conditions.

4. The Forest Service should commence a dialogue with environmentalist and outdoor sports groups to determine their needs that can be served as a part of this system. For example, the inclusion of emergency communications from remote sites, and emergency shelter in isolated areas.

5. That the Forest Service recognize that it is considering the placement of considerable equipment in isolated areas only reached by highly motivated and concerned environmental citizens who will probably take exception to the placement of this equipment in natural areas. Therefore, an environmental impact statement be prepared during 1973.
6. It is recommended that all remote site equipment be very carefully evaluated with regard to design to minimize environmental impact. This is a key recommendation.
7. It is recommended that a procedure be followed similar to that described above that allows the final system configuration to be the evaluatory result of further interactions between systems users, and systems designers.

Further detailed studies recommended as a part of the Field Test Program:

1. Additional study of battery types, and number versus the charger systems for isolated remote sites.
2. Engage in additional study of environmental impact problems associated with remote sites. Particularly such problems as shelter design versus packaged electronics and battery burial.
3. Define more carefully the library requirements for data at the Base Station, Regional Stations, and National Headquarters.
4. Evaluate the methods of sending routine data to National Headquarters rather than direct communications, i. e. mailing computer tapes.
5. Define more carefully other uses such as timber growth studies, timber sale computations, and general forestry requirements that could be served by the base station mini-computers.

6.0 REFERENCES

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